PRICE TEN SHILLINGS AND SIXPENCE.

THE JOURNAL OF The Institution of Electrical Engineers

ORIGINALLY

The Society of Telegraph Engineers

FOUNDED 1871

INCORPORATED BY ROYAL CHARTER 1921

EDITED BY P. F. ROWELL, SECRETARY

SAVOY PLACE, VICTORIA EMBANKMENT, LONDON, W.C.2

Telegrams: "VOLTAMPERE, PHONE, LONDON." Telephone: TEMPLE BAR 7676.

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COUNCIL, 1932–1933.

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[*Continued on page (III) of Cover.*

ELECTRIC LIGHTING OF BUILDINGS.

By A. B. READ and J. W. T. WALSH, M.A., D.Sc., Member.

[*Paper first received* 4*th December*, 1931, *and in final form* 12*th July*, 1932; *read before* THE INSTITUTION 3*rd November, before the* NORTH-WESTERN CENTRE 1*st November, before the* SCOTTISH CENTRE 8*th November, before the* NORTH-EASTERN CENTRE 14*th November, before the* SOUTH MIDLAND CENTRE 21*st November, before the* MERSEY AND NORTH WALES (LIVERPOOL) CENTRE 5*th December, and before the* EAST MIDLAND SUB-CENTRE 6*th December*, 1932, *also before the* IRISH CENTRE 19*th January*, 1933.]

SUMMARY.

Part 1 of the paper emphasizes the relationship between modern lighting design and contemporary practice in architecture and decoration, due to the use of new constructional methods and materials.

Various forms of lighting are described briefly, and instances are given, leading up to the more recent influence that lighting by electricity is bringing to bear on modern architectural form.

Part 2 deals with the characteristics of modern electric light sources and of the materials used in modern lighting, particularly diffusing glass of various kinds. The visual factors entering into lighting problems are then discussed, with particular reference to glare and its avoidance. The necessity for adequate contrasts, the proper utilization of shadows, and the importance of colour in lighting, are dealt with in the concluding paragraphs of the paper.

INTRODUCTION.

Not many years ago the illuminating engineer's principal aim was to provide as much light as possible for the very limited consumption of energy available, and to distribute this light as advantageously as he could. The luminous flux which could be obtained for a given rate of energy consumption was so low that there was generally but little margin available for dealing with the æsthetic side of lighting. It was the "foot-candle age" of illumination and the whole subject was dominated by tables of utilization factors, by the drawing-board, and by the slide-rule. Happily, thanks to the enormous progress which has been made in the means of light production during the past two or three decades, the whole aspect of the lighting art has undergone a complete change.

The first part of this paper describes some of the results which have been achieved in the field of illumination by those who have freed themselves from the trammels of tradition and have dared to lead expeditions of discovery into new and hitherto practically unexplored regions. The second part deals with the engineering and physiological principles which must necessarily govern design to some considerable extent, and it describes quite briefly the materials now available to the artist in light. A knowledge of the range of materials at his disposal and of their limitations is essential to every artist, and more especially to the exponent of an applied art such as illuminating engineering has now become.

Part 1.—THE RELATIONSHIP BETWEEN MODERN LIGHTING DESIGN AND CONTEMPORARY PRACTICE IN ARCHITECTURE AND DECORATION.

No new idea in science, industry, or art, is created in a perfected form; each begins its development in a crude and often unpromising way. The clumsy and criticized experiments of the past developed styles that became the veneration of later centuries, while the uninspired convention which was once applauded has since been forgotten.

The motor-car was an object of mirth until it was found to be useful, and a method of transport that was once a joke carries men and merchandise over every road in the world. Flying was madness a comparatively few years ago, while to-day it is a normal and safe occupation for thousands of men and women of all nationalities, and the full significance of its future is only beginning to be visualized.

When the world emerged from a war in which not only professional armies but whole populations had had life stripped of all save the bare facts and essentials of existence, it was not surprising that architecture, like other arts, should show signs of mistrusting the smug sentiment of conventional form. Possibly there was a mistrust of the monumental classicism that had been a symbol of strength out of which chaos had come upon the world.

After the war there was certainly a tremendous change in the character of architecture. The reasons that brought about this revolution are so highly debatable, and opinion is so widely divided about its results, that it would be folly to pursue the subject too far. However, the whole world has appreciated that there is a great truth and ideal underlying this new expression, and men with the finest brains and creative ability are striving to perfect a new style of honesty and utility. We have seen the birth of this new thought, and constructive criticism and intelligent use will bring about a style of which this generation and future ones will be proud. Changes such as this have necessarily affected all the products and services which are the servants of architecture. New proportions and new possibilities have utilized new products and inspired research in the use of old ones. New materials were to hand for architects to employ, and old rules and standards are now no longer always applicable. Great unsupported spans are possible, giving impressions to which our eyes are only now becoming adjusted. Fenestration following structural lines may be logically and usefully arranged in horizontal, undivided expanses quite unthought of and impossible a few years ago.

Our minds are not at all responsive to these new aspects of architecture, and prejudices and habit are not easily overcome. We are not surprised, therefore, when purity of expression is but seldom encountered and new buildings are springing up that have struggled ineffectively to free themselves of scraps of traditional or classic detail and usage which now look misapplied and incon-

gruous. Certainly we were slow to recognize that electric lighting, with its potentialities as a useful and decorative element in architecture, was worthy of real attention. We failed to see that we were cheating ourselves and cramping its powers by forcing it into forms that reflected little credit even on the illuminants it was replacing. For many years its adaptability was the greatest obstacle in its own path of development. Old chandeliers and lanterns were so easily adapted for electricity that the part it played in the lighting of interiors and exteriors was one of easily discernible deception. It threaded its way through hollow candles with permanent drips so easily that no one troubled to think about real design. Existing forms and the output of faked antique lighting fittings multiplied exceedingly, to satisfy the demands of the pseudo-traditionalists who were completely satisfied and who would regard the passing of such an institution as the candle, even though it were a metal one, as a national and universal calamity.

There were a few, however, who were finding that when problems were tackled boldly and with an open mind the solutions were somehow pleasing to the eye. They found something highly satisfactory about the lines of a motor-car when the designers had freed themselves from the clinging tradition of the coach-builder. The ship without sails acquired a grace entirely its own, and aeroplanes were found to be no less beautiful because they broke with the tradition of the air and dispensed with feathers.

These enlightened few, realizing that electricity possessed qualities and characteristics entirely different from earlier illuminants, turned their minds seriously to giving the new power a certain freedom to dictate its own forms and strove to bring about a closer and more harmonious alliance with the new movement in architecture and decoration. This alliance has become a matter that calls for the greatest concentration of thought and necessitates the closest co-operation between the electrical engineer and the architect.

Efficiency only in its fullest meaning is sufficient to satisfy the best minds of to-day, and this efficiency is a matter involving considerable æsthetic sense. Efficiency in all design must be accompanied by a reasonable economy and utility of construction; but, to produce results that are entirely satisfying, the designer must be conscious of the importance of form in order to make his product pleasing to the eye as well as practical in use. This true appreciation has produced all the great periods of the past, and is the only power that can give our generation a purity and beauty of style of its own.

Architects became more and more aware of the value of light, both natural and artificial, with the result that while windows became larger so electric light began to be introduced from sources forming an integral part of the interior scheme. This treatment was the logical one, but had been quite impossible until electricity had become available and had opened up a completely new field of adventure. It was easily installed, simple to operate, and safe, and, generating no fumes, the lamps could be enclosed with the minimum of ventilation. The lighting of buildings began to receive the attention it deserved and architects planned for light.

The time was coming when, quite apart from the actual electrical installation, the ultimate lighting of every part of a building resulted after every aspect of its position and function had been reviewed in the early stages of the setting out. Lighting was to be either a part of the architectural form or, if fittings were to be used, their positions had to be carefully decided upon in relation to their type and their place and importance in the general scheme.

Points are now provided, not for "a light of some sort" but either for a fitting in character with the room or to form a source as a feature of the construction itself.

In view of the general respect in which electric lighting is held by the progressive architects and decorators, and of the ever-growing possibilities it provides, it is easy to see why the form of fittings has acquired an architectural character. The architect has seen his project dignified and elevated by the emphatic or decorative power of light. Shapes of ceilings accentuated with bands of light; sweeping curves of auditoriums and corridors revealed and beautified; important entrances and doorways built, as it were, with light itself; magnificent scale or soaring height enhanced by lines of light. What glorious possibilities handled by an architect with vision; light which will serve him in a myriad ways; that can be quiet or blazing; that can reveal truth or lend mystery by its degree of strength or colour; light that has become the most important decorative factor in modern decoration.

It is this vision and use of lighting in an architectural form which has brought about another architectural revolution of which the world is only now beginning to be aware. Electric lighting is not only being regarded as a necessary and decorative feature to be considered in the designing of buildings, but is becoming the *raison d'être* of new architectural form. All interiors must be artificially lit, some for longer periods of the day and year than others; the use of floors below street-level are made possible only by electric lighting and ventilation; while many big public buildings such as cinemas, theatres, concert halls, and restaurants, either purposely exclude daylight or are used only at night. As artificial light makes their use possible, it is not surprising that this element is productive of such careful thought and experiment on the part of the architect that, after the dictates of the function of the building and the limitations of site and building restrictions have been dealt with, it becomes to a great extent responsible for the interior and exterior form of the building itself.

In this respect some of the Continental countries have shown greater courage than ours, and there are excellent examples which not only have withstood the world's criticism but have been accepted as great and splendid achievements worthy of the best architectural traditions. No great school of thought is without its followers who, with no true feeling for the essential truth, debase, for mean and narrow commercial ends, a vigorous and honest style to the level of a cheap and fleeting fashion. The world is not likely to confuse high endeavour with tawdry imitation, and the next generation will recognize the courage of fine experiment and the real dignity which more and more of the modern buildings of all kinds throughout the world have acquired by the right employment of electric lighting. Certain it is that we

are becoming light-conscious, and in any important scheme the practice of providing a number of lighting points by cursory glances at plans of buildings already in course of construction will soon be regarded as ridiculous and disastrous as to decide positions of windows and staircases after the steelwork of a building has been erected.

Examples will be described in the paper to illustrate this influence of modern lighting in interior and exterior forms of architecture—forms and characteristics that must of necessity be without precedent.

Home Lighting.

In reviewing the application of architectural lighting in the home we must turn to those houses which are, so to speak, prophetic of a tendency that, in a modified form, will become more and more a common practice throughout the homes of the world. All affairs nowadays have lost much of their insularity and, with the interdependence of the nations and the amazing development of communications and exchange of thought, all discovery and invention have become universal property.

Electricity is thus at the service of the whole of the civilized world, with the result that the new creative principle finds, in all parts of the globe, disciples who have adapted it to their special needs and conditions. These homes, which are the heralds of a movement that will become general in the near future, are not necessarily created by those who are in a financial position to make rash experiments. Where there is more money to spare for the purpose, the decorative scheme and lighting are possibly more intricate or extensive, but there is an ever-growing number of small houses lived in by men and women of moderate means who have made opportunities for introducing simple features with light that have added charm and character to what would otherwise have been stereotyped and dull interiors. Instead of spending the greater proportion of money on the actual wall decoration and furnishings, it has been found that thought given to lighting and its installation has brought life and interest which could have been produced in no other way. When houses are being built or flats redecorated, the nucleus of the scheme is often to be found in the lighting, considered in relation to the purpose of the room, from which wall or ceiling forms, colours, and textures, and even arrangements of furniture, have followed naturally, retaining thereby a unity of character.

The obvious purpose of electric light is to illuminate, but there are innumerable ways of employing it to form an architectural unit or surface of a room to give, in addition to its practical illumination, by its shape and its effect, considerable æsthetic satisfaction. This system of using light architecturally is definitely divided into three classes: direct, totally indirect, and a combination of the two methods.

In the first class are to be found panels of glass often in the same plane as the ceiling or walls, forming sides or tops of recesses and soffits; rectangular or curved section members of glass built as surfaces or bands on ceilings, or at the junction of ceiling and walls; as vertical or horizontal panels of stepped ceilings, returns of door recesses and pilaster forms on walls, or forming corner features at intersections of wall planes. Of their very nature as architectural elements, these light sources have an austerity which has wrung wails from the humanists who, seeing nothing but robot standardization and inhumanism in this mechanized age, deplore the passing of the romanticism of delicate candelabra and their appropriate settings. To have a faith in the eventual goal of progress means no hasty forgetfulness or lack of appreciation of the glorious periods of architectural history and the fine achievements of exquisite refinement they produced. Certain canons of proportion and appropriateness are eternally applicable, but if science provides mankind with a great discovery it is not the fault of science, but of mankind, if it is misapplied.

It is a curious fact that we unceasingly concentrate in a short-sighted way on the perfecting of industrial processes and production, while being rather careless of their ultimate employment. Here we have an intricate system of installation, cables, switches, and lamps, all representing the products of long research and experiment by scientists and engineers of high standing, to operate features of lighting often crudely conceived. If electric lighting is to bring honour upon itself it must be handled with sensitiveness and a sense of proportion. In the final effect harmony and unity of conception must be preserved, and, to achieve this, engineering science must be directed with restraint and taste. There is a tendency, through over-enthusiasm and familiarity with modern methods of lighting, to serve up feasts of illumination cunningly and painstakingly prepared which we are unable to digest.

It is not in the homes of the rich or the highly intellectual that the best decoration or lighting is to be found, but generally in houses and flats occupied by intelligent people whose views on lighting as on other important matters are unprejudiced and progressive. They furnish not to impress their friends or to gain notoriety, but for the reason that they enjoy their surroundings. They judge period or modern work by the same standards, and their desire to possess either is influenced only by the standard of design. They do not like things more because these are old, or less because they are new, and they are interested in the new qualities of lighting because it can be introduced for new use and pleasure in their homes. They are particularly concerned with the problem of how best to adapt this wonderful power to their own requirements, to illuminate each room in the house in the best possible way with electric light, and to introduce with thought and discretion this power for good that really exerts such a tremendous influence on their health and moods.

As the form and colour of rooms gives an infinity of variety, so architectural lighting allows of unlimited interpretation. The direct method of architectural lighting is most suitable for the porch, the hall, the dining-room, corridors, and the bathroom. Lighting units can be built into the junction of the porch and the wall over the door; panels can form the soffits of door recesses, or two vertical units can be built one on each side, forming a part of the architectural setting of the entrance. In the hall and bathroom, panels of glass of a suitable size can often be easily formed in the ceiling.

These panels may, by their shape, accentuate length or direction. They may be on the same plane as the ceiling, giving direct light only below, or a few inches below, ceiling-level, so that light from the open or glazed sides can illuminate the ceiling. These glazed sides by their colour can blend with the wall, while, through more translucent or whiter glass bases, strong light can be thrown downwards. For the dining-room this is specially suitable, as the table is lit more strongly than the ceiling or walls, and the panel itself repeats the position in plan of the dining table. Being on ceiling-level, this form of lighting is well above the normal line of sight, and light is so well directed that one is not aware of its source. By judicious arrangement of lamps and switching, several intensities of light can be used, giving a quality of illumination to suit one's mood or company. The serving table, even in old houses, is often in a recess, and the top of this can house a panel or unit of glass giving direct lighting for service but not competing in importance with the main lighting of the room.

In the bathroom, lighting fittings have always tended to become a part of the room and to project as little as possible. Architectural lighting carries the principle a stage further. It is essentially a clean, constructive way of lighting, leaving, as it does, plain smooth surfaces with surrounds of stainless metal or porcelain. General light can be introduced from ceiling or wall panels, and soffits of recesses and cupboards can be illuminated, with purposeful and decorative results. The mirror even can be built into the wall and be self-illuminated by the "halo" method, or have boxes or panels of light above, at the sides, or, especially for shaving, from below.

The kitchen could also be illuminated on these lines, especially when the ceiling is low; and even the efficiency fittings which are used for kitchens, sculleries, and pantries, have become so simple in shape as to be called "architectural." There is a great range of these fittings which, with porcelain backs and screw-in glasses, cling as closely as possible to walls and ceilings, and are quite different in character from the older types with their projecting arms and dust-collecting galleries.

The sitting-room and lounge lend themselves to indirect methods of lighting. The earlier practice of using the cornice as a screen, from behind which light is thrown on to the ceiling and by reflection to the walls to produce a general illumination, is still applied successfully, but success has very largely depended on the section of the ceiling and the curve of the cove above the light source. It follows that where cornice lighting is introduced into existing rooms the results are speculative and often unpleasant, but in rooms that have been specially designed the effect amply justifies its employment. Above and below the cornice line there is often a severe division of tone which tends to give a cramped and closed feeling to the room, as if one were standing in a rather dim walled enclosure with a brilliant light outside. This fact and the long perimeter (necessitating a greater number of lamps) has led to experiments with indirect lighting from the centre of the ceiling with carefully shaped surrounding ceiling and junctions with the walls, calculated to catch and reflect the light. This fascinating means of illumination, which provides limitless scope for giving beauty of form and lighting, is, of course, in a direct line of descent from the dish fitting. It has ceased to be a fitting but has become an architectural element so unlike and so civilized as to bear no resemblance to its prototype. The main principle involved is a central panel with lamps above, the light from which is directed by suitable reflectors on to a ceiling, the section of which has been designed to reflect light into the room. This panel may be a single or many-tiered one, its plan rectangular or any shape that suits the character of the room, and the surrounding ceiling can be shaped both in plan and in section to give a thousand and one degrees of light or shade. The beauty lies not only in the play of light on the line and form of the ceiling but in the unbroken luminosity of the walls, the section of which follows in an uninterrupted series of straight lines or curves from the floor to the central light source itself.

Though generally used for the rooms mentioned, the employment of this indirect principle is one of personal taste and is not unsuited to any room of the house where shapes and conditions allow. Sometimes translucent elements are introduced into schemes such as this to provide a direct as well as an indirect light. Where a cornice is made in glass there is direct light through the glass and reflected light from the walls or ceiling above. Personal requirements and habit demand such definite degrees of light that this combined method of direct and indirect lighting is often used in sitting-rooms where direct light for reading or working is needed, in addition to the general diffused light from the indirect source.

Light can be concealed behind architectural wall features or thrown on to coved ceilings or coved recesses, in an infinity of ways. Rooms can be illuminated by light thrown upwards from truncated pilasters or island standards, the ceiling acting as reflector.

All these possibilities can be successfully used by intelligent co-operation between designers, architects, and engineers. The results from all these means of illumination can, however, be as uninteresting as they can be intriguing.

PUBLIC BUILDINGS.

This new attitude towards the importance of lighting in the home has followed from the interest that the large public buildings have attracted to themselves by the beauty of architectural light. The big cinemas and theatres, the hotels and restaurants, shops big and small, have been designed and illuminated as the result of considerable thought and experiment, and the churches have benefited by the new beauty of lighting expertly and sensitively used. Big commercial concerns were among the first to realize the qualities of this new lighting, and, being in a strong financial position, have been the leaders in its employment. Much of the lighting of private houses has been directly traceable to this world-wide use of light as a feature of very great interest and importance in the big buildings erected in the past few years for public entertainment. Whereas official architecture has, in this country at any rate, remained classical, the architecture of commerce is exemplified by the factories, offices, shops, and buildings such

as hotels, restaurants, cinemas, and theatres, which have been erected, as a result of great commercial enterprise, to cater for populations who are nowadays of necessity associated in or dependent on commerce; all these have a certain vital quality and have accepted architectural lighting as a fact to be made use of to the fullest extent in relation to their use and character. It is safe to say that this use of light had been a practice more common on the Continent than here, and it was from the Continent that the new concept of light architecturally used spread throughout all the countries of the civilized world. Paris six years ago, following the installation of a few examples of lighting from existing cornices and laylights, was a revelation. The Chiquito Restaurant with its ship-like character and illuminated plaster and glass ceiling and fish tanks; the Bar Bresil with its dome ceiling perfectly lit from the central pendantive and an outer ring of light; the Bar Bèrgère with its heavy glass external pilasters of light and glass-topped bar; the Portiques on the Champs Élysées with an immense ceiling of glass; the Salle Pleyel; the new houses and the countless shops and restaurants all lit by electricity in ways which gave even the architecture itself a new significance. There was much that was bad and crudely installed, but there were obviously the beginnings of a new attitude towards the treatment of light. There were the signs of a liaison between lighting science and art, and architecture and decoration were acquiring thereby a new dignity and impressiveness. There was to be an architecture of light.

Theatres which are designed for stage or screen shows have auditoriums formed with lighting as an integral feature, emphasizing their form. Their architects would admit that their conceptions have been inspired, or at least greatly influenced, not by matters of style but of light. As the form of an auditorium—which should be the satisfactory solution of problems involving limitations of seating, sight lines, and regulations of all kinds—can acquire a dramatic quality, so the perfect introduction of light flowing from the very form of the interior, by its position, strength and colour giving a definite scale of value of illumination or texture, can provide the exact embodiment of an idea, and give an impressiveness and definite emotional direction hitherto undreamt of.

The Titania Palast in Berlin was perhaps the best-known example of an auditorium and proscenium designed as an architectural unity with the swirling lines of the indirect lighting primarily conceived for this dramatic effect. The lines of light seem to swing one's attention to the screen, which is the focal point. In the Kino Universum, Berlin, a much discussed and criticized design, the coved illuminated panels on the ceiling of the auditorium, though so straight and unrelieved, have this same directional quality with less disturbing effect.

With all their aggressiveness and what, to many, is a sort of architectural brutality, these two cinemas have that unity of design and subordination of everything, including light, to the accomplishment of a crystallized idea. The tendency has been, when exploiting the possibilities of lighting, to be led into a series of effects each interesting in itself but competing with the main theme—to use light for cunning effects rather than as a cumulative element of the whole character of the building. It is this spontaneous quality of light that, developing logically from a great architectural conception and being, as it were, the very life of architectural form, will be the basis of illumination of the great buildings of the future. Light used as an incident has the status of the drawing-room ornament; light used as an inspired and vital element in architectural design evokes the greatest respect and admiration.

Lighting by electricity has an almost incredible versatility. The methods which can enhance the devotional and restful atmosphere of a place of worship, further dignify a great public building, or be a useful and decorative element in a small private house, can breathe sobriety in one restaurant, yet bring sparkle and gaiety to another. Some Continental examples are well known. A famous restaurant in Berlin has illuminated columns, fish-pond glass ceilings, and great features of glass tubes and rods all designed as a part of a highly successful but amusing idea.

Neon tubing, following the architectural fan-shape radiating lines of the ceiling, was in use two years ago in a Berlin café, and it seems that here is another element in modern lighting that may bring about another re-adjustment of lighting practice.

The shop designers have availed themselves of all the lighting methods at their disposal, and, although the big stores are not noteworthy in this respect, there are many very attractive smaller shops.

Lighting has influenced the exterior design of these shops and stores to as great an extent as that of their interiors.

Light concealed, or as canopies or bands of glass, has been introduced as a great feature governing the arrangement and texture of whole façades, while the inclusion of the name of the shop is treated frankly and with the importance it deserves both for daylight and for artificial illumination, and not, as so often happens, as an afterthought.

The great glass canopy of the Galeries Lafayette in Paris, built several years ago, is a well-known example of the mass effectiveness of light as an architectural form, and is, incidentally, a wonderful form of advertisement. The canopy over the entrance at Selfridge's in London is of this same character but of much smaller dimensions. The better treatments are those that are more severely architectural and less intricate in design. Intricacy with light on the front of the great building is out of place, and too much delicacy of detail is bound to be dwarfed or obliterated.

It is still rare to find a building, whether it be a shop or a cinema, that has been designed with all the essential requirements of light effect, name illumination, space for announcements, etc., adequately considered. Lighting will play a growing part in the exterior design of many buildings, including the shops and big stores, and the sooner this is recognized the sooner will disappear those straggling signs and notices which could be so sensibly incorporated in the original design.

The development of floodlighting has necessitated a further reason for consideration of the requirements for effective incorporation of lighting as an external factor in design.

Passenger ships have occupied the time and attention of a great many architects and decorators, and their work is coming under the notice of a travelling public that is becoming more educated and critical. It is not within the sphere of this paper to discuss the appropriateness of dining-rooms decorated in the eighteenth-century manner, or Jacobean smoking-rooms, for great liners whose hulls and motive power are the products of twentieth-century science and engineering skill. There may even be some fanatics for the antique who would wish to introduce their panelling, enriched plaster work, and Knowle chandeliers, into the new air liners. However, the majority of the other nations have brought intelligence and common sense to bear upon this more important matter of suitability, and the "Ile de France," "Bremen," and "Europa," have rooms treated in such a manner as to preserve the graceful ship-like characteristics that are apparent externally.

Indirect lighting from shaped ceilings, direct lighting from glass channels interestingly treated, light from fittings built into corners all sensibly and suitably designed, form, with their modern settings, a background to the life on board more related to contemporary ideas and the ship itself.

It seems a pity that there should be a reluctance in the case of some of the decorators of our own bigger ships to depart from this pseudo-period tradition which has been handed down from the hotels on land to their floating equivalents.

The lantern slides should make clear a good many of the points mentioned in the paper. The fact that must be emphasized is that architectural lighting will develop in the right way only as the general attitude towards contemporary architectural experiment becomes more sympathetic and selective. This sympathy does not imply a lessening of our reverence for the great styles of the past, but should increase our appreciation of all the courage and thought that has given birth to what may become a tradition for posterity.

Part 2.—THE ENGINEERING AND PHYSIOLOGICAL ASPECTS OF LIGHTING.

The foregoing description of the accomplishments of the new school of illuminating engineering presents a picture of results which not many years ago would probably have seemed altogether outside the realm of practical politics. It is only the rapid improvement which has taken place comparatively recently in the means for light production that has made the achievement of these beautiful effects possible to-day, so that it may not be out of place to consider briefly the properties of some of the materials now available to the lighting engineer.

There is first the actual light source, now almost universally the tungsten-filament gas-filled lamp. This lamp has both advantages and disadvantages as compared with its predecessors, when judged from the lighting engineer's point of view. One of its great advantages is its high luminous efficiency. The 100-watt gas-filled lamp of to-day gives 1 160 lumens, as compared with the 890 lumens of the vacuum lamp and the 350 to 400 lumens of the best type of carbon-filament lamp. A further advantage, for many purposes, is the concentration of the filament into a comparatively small space. This concentration, when accompanied by proper standardization of the filament position in relation to the lamp cap, enables the designer of a fitting to make use of optical devices for redirecting the light if he so desires, and in many fittings the best effect is obtained only if a lamp of the correct size is accurately positioned in the fitting.

The chief disadvantage of the gas-filled lamp is the very high temperature at which the filament operates, and the consequent high brightness of the naked source. An attempt to overcome this disadvantage has been made by obscuring the bulb of the lamp, either by the use of opal glass or by the frosting of the internal surface of the clear glass bulb. The effect of such internal frosting on the efficiency of the lamp as a light-emitter is very small, but it naturally prevents the use of the lamp in conjunction with any optical device depending on the employment of a source of small dimensions. Further, it seems to be quite generally accepted that the use of a diffusing bulb overcomes all difficulties due to the high brightness of the filament. When, however, it is considered that the *average* brightness of the bulb itself is about 13 candles per sq. in. (and the central portion of an internally frosted bulb is considerably brighter than the peripheral portions), whereas the limit of brightness specified in B.S.S. No. 324 for a diffusing glassware fitting is 3 candles per sq. in., it will be immediately apparent that no portion of a diffusing lamp bulb should normally be permitted to come within the field of view.

On the other hand, for use in diffusing panels and many decorative fittings, the opal or internally frosted bulb presents the great advantage that the effective light source is large and there is consequently less likelihood of "spottiness" when using a given diffusing material for the panel or fitting. Putting the same thing the other way round, we may say that the use of diffusing bulbs allows a more lightly diffusing material to be used for the fitting.

In a number of modern lighting fittings a formerly much-despised cinderella of the lamp-making industry has found an important role. The tubular lamp, which was, until recently, used almost exclusively for show-cases and similar purposes, is now finding so many applications in modern lighting that it has at long last been decided to introduce some much-needed standardization into its manufacture.

Mention of the tubular-filament lamp leads naturally to a brief reference to the latest development in light production, the gaseous discharge tube. For many years this form of lamp was very severely restricted in its application, and until quite recently it was used almost exclusively for advertising signs, the type employed being generally the neon tube with its deep red light. Within the last few years, however, other forms of discharge tube have been developed with astonishing success. The introduction of the hot-cathode lamp will make it possible to work with ordinary supply voltages across the tube, and the use of various mixtures of the rare gases provides a wonderful range of hues in the

light available. Further, the efficiency has been greatly improved, and with the sodium-vapour lamp, giving the bright yellow light usually associated with the sodium flame, a luminous efficiency of about 30 to 50 lumens per watt is obtainable.

Of course the use of lights of very pronounced colours has many objections from the lighting engineer's point of view, and discharge tubes will probably not find their way into general use until this defect is overcome. There are two possible lines of attack on this problem. One is the development of a new form of tube giving light which is approximately white in colour: the other is the use of two or more tubes of different kinds side-by-side so that the blend of the lights gives some approximation to white, at any rate as far as the visual sensation is concerned. Even at the present stage of development, a fair approximation to a white light is obtainable by the use of a red neon tube and a mercury-vapour tube. There seems to be some fruitful ground here which the designer of modern lighting fittings might usefully cultivate. Surely there must be something attractive to him about a source of light in the form of a strip of considerable length and, moreover, a strip which can be bent into an almost unlimited variety of forms. It is difficult to imagine a source of light more pliable in the hands of both the artist and the illuminating engineer.

Diffusing Materials.

Passing now from the light source itself to the other essential element in a lighting device, the diffusing material, we are at once bound to consider that very widely-used and yet most tantalizing and uncontrollable material, opal glass. Even in the case of ordinary glass it is not easy to control with any great degree of nicety the performance as regards light transmission, and when the nature and mode of manufacture of opal glass are considered it is small wonder that reproducibility is extremely difficult to achieve. Speaking generally, it may be said that the diffusing properties of opal glass are due to small particles of calcium fluoride embedded within a matrix of ordinary glass. What the designer of a lighting fitting usually desires is a maximum of diffusing power combined with a minimum loss of light in the glass. He may also be interested in the relative amounts of the incident light which are respectively transmitted and reflected from the glass. In the case of, say, a totally enclosed lighting fitting in which by far the greater portion of the total area of the fitting consists of glass, the chief matter of interest is the absorption. A high reflection factor means that more of the light from the lamp is reflected back and forth within the fitting before it finally emerges, but this is comparatively unimportant if the loss at each inside reflection is only small. Matters are quite different, however, if the glass occupies, say, less than half of the area of the fitting. In the case of a panel, for instance, the lamps are enclosed in a box which is probably rectangular in shape and of which the back and sides are composed of some opaque material covered with a white paint or enamel. If the total area of the back and sides of the enclosure be double the area of the glass panel, and if the reflection factor of the internal surface be 80 per cent, the light reflected back into the enclosure from the inside surface of the glass will suffer a considerable loss. In fact, if the absorption of the glass panel be taken as zero and if the transmission factor be 60 per cent and the reflection factor 40 per cent, the light emitted will be about 30 per cent more than if the transmission factor were only 40 per cent and the reflection factor 60 per cent.

There are three principal factors which determine the performance of an opal glass. These are (*a*) the size of the particles and their nature (e.g. the refractive index relative to that of the body of the material); (*b*) the number of particles per unit volume; and (*c*) the absorption of the glass matrix. The last-named factor is far more important in opal glass than in ordinary glass, because the light is reflected many times between the particles and so its path within the glass is greatly increased. In many glasses iron is present as an impurity, and the resultant green coloration may be corrected by the addition of manganese. The colour correction, however, is obtained at the expense of increased absorption, so that the material used for opal glass should be as free as possible from iron and other impurities likely to reduce the transmission factor of the material. The effect of variation in the size and concentration of the particles is to alter the degree of diffusion produced by a given thickness of the opal. Speaking generally, the larger the particles the better is the diffusion for a given value of transmission factor, or, alternatively, the higher is the transmission for a given degree of diffusion.

It may be useful to mention here that there is at present no agreed method of describing by means of a single figure the diffusing power of a material such as opal glass. The term "perfect diffuser" is usually employed to describe the ideal material which, however the light incident upon it is distributed, has a uniform brightness whatever be the direction from which it is viewed. Such diffusion has been shown to be unattainable in practice with a glass having polished surfaces,* and actually it is quite unnecessary for ordinary purposes. A much less "perfect" diffusion is quite adequate for lighting fittings, and it has been proposed that the quality of an opal glass shall be described by the transmission of the glass when used in a thickness such that the filament of an electric incandescent lamp ceases to be visible through the glass when the lamp is placed at a specified distance behind it. The value of transmission which it is convenient to employ is that given by the efficiency of a spherical bowl of the glass. This "efficiency" is defined as the flux emitted by the bowl when expressed as a fraction (percentage) of the flux emitted by the lamp inside the bowl.

There are, of course, many materials other than opal glass which are used by the illuminating engineer for diffusing or redistributing the light from the lamps. Frosted glass, acid-etched or sand-blasted either uniformly or in some design, is, after opal glass, the most commonly used material for producing diffusion by transmission. The amount of light lost in such a material is so small as to be almost negligible for all

* J. S. Preston: "The Properties of Diffusing Glasses, with Special Reference to Surface Effects," *Proceedings of the Illumination Congress*, 1931, vol. 1, p. 373.

practical purposes. Prismatic glassware, or clear glass moulded or cut in various decorative designs, may also be regarded as absorbing practically none of the light that it receives.

In some systems of lighting the luminous flux from the lamp is not diffused by transmission but by reflection from some matt surface. This may be a ceiling, a shade or reflector, or some specially designed architectural feature so placed as to receive the light from the lamps and redistribute it in such a way as to produce a very "soft" lighting effect. It is difficult to maintain a matt white surface with a higher reflection factor than 80 per cent, and in most cases, especially when the tone of the decoration is not perfectly white, a figure of 60 per cent is usually the best that can be maintained for any length of time. Such a system of lighting requires constant and careful attention to its proper maintenance if the efficiency is not to be allowed to fall to an unduly low figure.

The Visual Factor.

So far, in this part of the paper, the authors have given a brief survey of what may be regarded as the strictly engineering side of their subject; but it must never be forgotten that the illuminating engineer's real master is the human eye. No lighting system, however efficient it may be as measured in terms of the illumination produced per watt per square foot of floor space, is really satisfactory unless the eyes of those who have to live and work under that lighting system are enabled to do the tasks required of them satisfactorily and with the smallest possible amount of fatigue. Similarly, the most pleasing and æsthetically satisfying system of illumination fails under one of the most critical tests which can be applied to the work of any creative artist, viz. that of fitness for the function it has to perform, if the light provided is inadequate or if the eye cannot, by means of it, carry on its work efficiently and without any sense of strain or trace of discomfort.

It is at this stage that the illuminating engineer finds himself in a very grave difficulty. The excellence of his work must, to a large extent, be judged by the absence of any discomfort or undue fatigue on the part of those who have to work by the lighting system he provides. Yet he has no instrument by which either discomfort or fatigue can be measured even to the roughest approximation. In this quandary he turns to the physiologist and to the psychologist for their advice and assistance, and his disappointment is great when he finds that they, too, have no means at their disposal for obtaining any reliable measurement of fatigue. Every illuminating engineer is only too familiar with the many researches which have been carried out on this subject, most of them by physicists or engineers who had little appreciation of the psychological factors involved. Not unnaturally, the results obtained are almost as various as the tests employed. In every case, of course, it is found that the ease with which a given task can be performed is much less when the illumination is low than when it is high, but "there needs no ghost, my lord, come from the grave to tell us this." The curve giving the quality of the performance as a function of the illumination always shows a flattening-out at the upper end, but the value of illumination at which this flattening begins to take place depends not only on the visual task employed in the test (that is only to be expected) but also on the scale chosen for plotting the curve.

The truth of the matter is that the human body has a wonderful adaptability and a large reserve of vitality upon which it draws when any unusual demand is made upon it. Sometimes it even draws on this reserve to an amount which is in excess of that actually required to meet the exceptional demand, and it is occasionally found that the performance is improved when the conditions are made more exacting.

It will be seen from this that a very difficult task faces the illuminating engineer when he attempts to collect reliable evidence as regards the effect of varying any given factor in lighting. An attempt has been made to attack the problem along quite different lines and to assess the effect of different factors by a simple qualitative comparison of two lighting systems differing in some particular respect. The comparison is made by a large number of observers, and their opinions are collected and analysed to see whether there is any more or less general agreement among them. An investigation of this kind was carried out in 1930 at Leicester by Dr. W. S. Stiles, who obtained comparisons between a number of different systems of street-lighting by analysing the opinions expressed by a number of public lighting engineers and others specially interested in the subject. In a critical survey of this method as applied to the problem of assessing glare,* he came to the conclusion that the observers paid more attention to the discomfort effect than to any actual interference with visual performance. It would be very interesting to have similar experiments carried out on other lighting problems, e.g. those connected with factories, schools, offices, libraries, etc.

Glare.

One of the chief factors in determining the excellence or otherwise of a lighting system is that which has just been mentioned, viz. glare, and the two effects which it produces are now commonly differentiated under the names "discomfort glare" and "disability glare." A great deal of work has been done by Dr. Stiles and others on the measurement of "disability glare," and his researches† have led to some fairly definite conclusions as to the extent to which the presence of a glaring source in the field of view lowers the capacity of the eye to perceive a given degree of contrast. If this power of perceiving contrast be taken as a measure of the efficiency of the eye under any given lighting system, it is comparatively easy to express the deleterious effects of glare in terms of the equivalent reduction of the general level of illumination.

The matter will be made clearer by considering an example. Over quite a considerable range of brightness, from that of white paper under an illumination of

* W. S. Stiles: "Mass Experiments in Street-Lighting," *Proceedings of the International Illumination Congress*, 1931, vol. 1, p. 576.

† W. S. Stiles: *Proceedings of the Royal Society*, (B), 1929, vol. 104, p. 322; also *Illuminating Engineer*, 1929, vol. 22, pp. 304 and 311; and "The Effect of Glare on the Brightness Difference Threshold," Illumination Research Technical Paper No. 9 (H.M. Stationery Office, 1929).

0·4 foot-candle upwards, the eye is just capable of detecting a brightness contrast of about 1 per cent. Thus if the illumination on a piece of white material be 0·4 foot-candle, a thread or patch which is 1 per cent darker than the remainder can just be detected. If, however, the illumination be reduced to 0·04 foot-candle, a greater degree of contrast, viz. 2 per cent, is necessary before the eye can detect any difference. Similarly, as the illumination is decreased still further, the degree of contrast necessary for perception rises

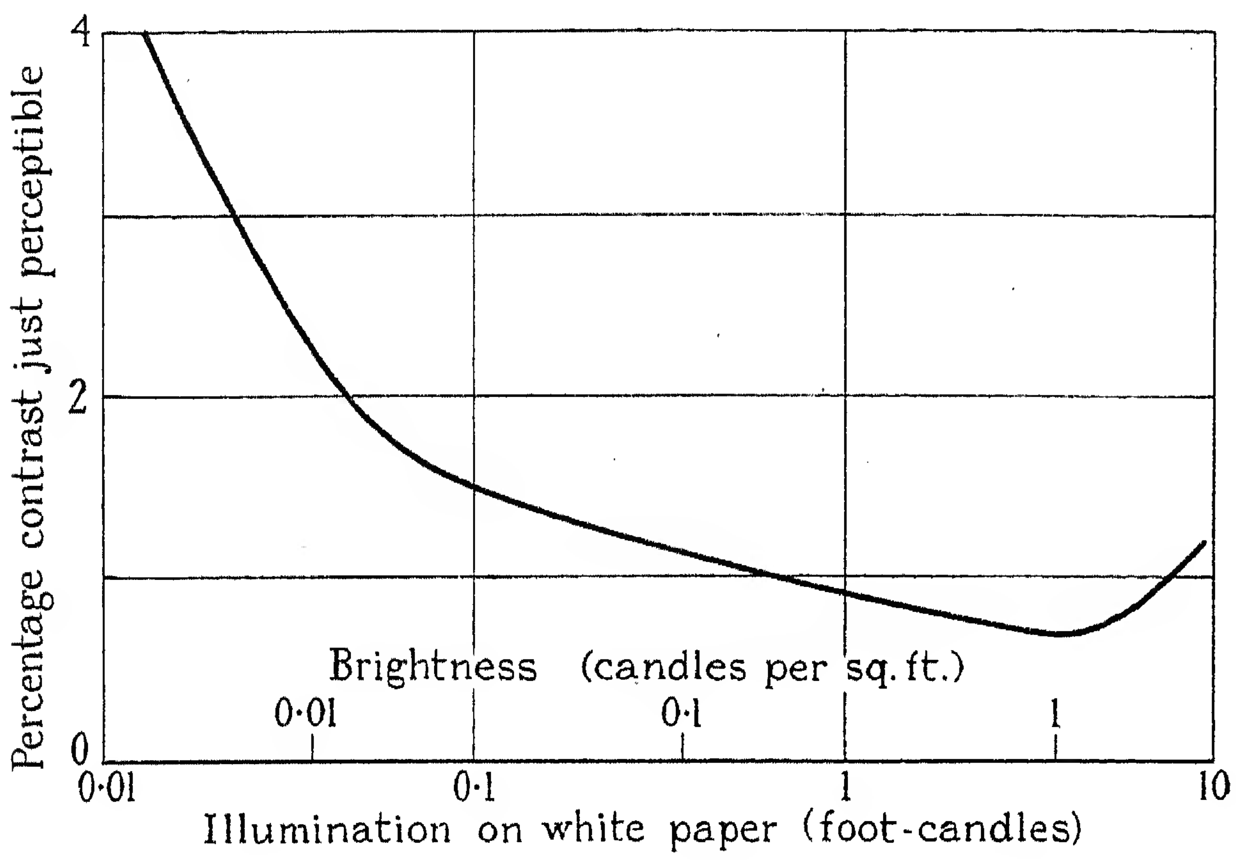

FIG. 1.

more and more, as shown in Fig. 1. All the values so far referred to are those which apply when no glare whatever is present in the field of view. If, now, a bright source of light be visible at the same time as the object under observation, the sensitivity of the eye is reduced and hence the least degree of contrast which can just be seen is larger than before. The experimental results show that the effect of a glaring source depends on two things, (*a*) the illumination E which that source produces at the observer's eye, and (*b*) the angular distance θ between the glaring source and the object looked at. The effect of the glare, taking account of both these factors, varies as a function of $E/\theta^{3/2}$.

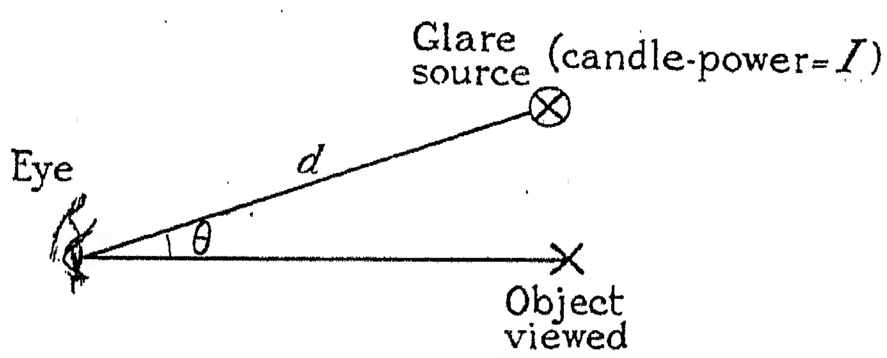

FIG. 2.

Glare effect $\propto E/\theta^{3/2}$, where $E = I/d^2$

Fig. 2 will explain matters more clearly. The method now generally adopted to express the results of any given glare is to multiply the function $E/\theta^{3/2}$ by a constant (actually 4·16 when E is expressed in foot-candles and θ in degrees) and to add this to the actual brightness of the field of view. The resultant sum is called the "equivalent background brightness," and a fraction of this (1 per cent for all normal values of brightness) is the actual brightness *difference* (not percentage contrast) which can just be perceived. This difference is naturally higher than the difference perceptible at the actual field brightness, and in fact when it is expressed as a *percentage* of that field brightness the resultant figure is considerably greater than the 1 per cent corresponding to conditions of no glare.

This result may be regarded from two points of view. In the first place it may be said that, with the glare present, contrasts must be increased so many times before they become as noticeable as when there was no glare. Alternatively, it may be said that the least contrast perceptible when the glare is present is the same as that just perceptible when the brightness of the field of view is such-and-such a fraction of its real value but with no glaring source visible.

A simple numerical example will make matters clearer. Let the brightness of the object looked at be 1 candle per sq. ft., i.e. suppose that it is white paper or cloth with an illumination of 4 foot-candles. Suppose, further, that the glaring source is a 100-watt lamp (100 candle-power) at a distance of 8 ft. from the observer and at an angular distance of 9° from the line of fixation. In this case $E/\theta^{3/2} = (100/8^2)/9^{3/2} = 0{\cdot}058$. Thus the equivalent background brightness is $1 + (4{\cdot}16 \times 0{\cdot}058) = 1{\cdot}24$ candle per sq. ft. The minimum contrast perceptible at this brightness being 1 per cent, i.e. 0·0124 candle per sq. ft., it is 1·24 per cent of the actual brightness (1 candle per sq. ft.). Thus the minimum perceptible contrast has been increased by 24 per cent of its original value. It will be seen from Fig. 1 that, in the region of $B = 1$ candle per sq. ft., a decrease of about 25 to 30 per cent in the field brightness produces an increase of 24 per cent in the minimum perceptible contrast, so that we may say that, for perceiving contrasts on a white background, the actual system with the glare present is only as good as one in which the brightness is 25 to 30 per cent less but in which glare is avoided. In other words, the presence of the glaring source has reduced the efficiency of the lighting system at the point under consideration by 25 to 30 per cent as far as work on a white surface is concerned.

If the surface, instead of having a high reflection factor, were dark (reflection factor of 8 per cent, say), the brightness would be only 0·1 candle per sq. ft. In this case the equivalent background brightness corresponding to the glare conditions would be $0{\cdot}1 + 0{\cdot}24 = 0{\cdot}34$ candle per sq. ft., and the minimum contrast perceptible, 1 per cent, would be 0·0034 candle per sq. ft. This is 3·4 per cent of 0·1 candle per sq. ft., so that the minimum contrast actually perceptible with the glare present is 3·4 per cent, i.e. the same as that perceptible with a field brightness of 0·005 candle per sq. ft. in the absence of glare. In this case, then, the presence of the glaring source has reduced the lighting system to equivalence with one giving only 5 per cent of the illumination actually provided. Other conditions of glare and of field brightness may be worked out by the same method, using the formula given above ($4{\cdot}16\ E/\theta^{3/2}$) and the curve of Fig. 1. Some very striking and instructive results can be obtained in this way.

CONTRAST.

Among all the problems of lighting practice, glare has received by far the greatest degree of attention from

—is at times raw and often uncouth. It is very necessary that the architect should be a more imaginative designer; but it is also essential that all three—the client, the architect, and the engineer—should have a definite idea of what they intend to produce. There is scarcely any idea of incorporating attraction in advertisement signs, for example. There is a lack of public spirit in design: the aim is to sell, to show something, but not to create an æsthetic appeal. Until that sentiment is there, I do not think we shall get the progress for which we should strive. As an aid to decoration, light is still in its infancy. The gaseous discharge tube is very little used except in the form of a straight line, and occasionally as a circle; the idea of using it to create patterns is still in its infancy, except in Paris.

Mr. T. P. Bennett: I have just come back from Berlin, Prague, and Vienna, where I have examined some of the latest electric lighting effects. I inspected in Berlin comparable systems of lighting with ascertained energy consumptions, and I was told that to secure reasonable illumination by an entirely indirect system 6 000 watts were used where 3 000 watts of semi-indirect lighting had previously been employed; moreover, a further 3 000 watts were introduced in order that the rather flat and toneless appearance of the room in question might be enlivened by some visible lighting sources with low surface intensity of illumination. In other words, the so-called perfect system had a consumption of 9 000 watts where formerly 3 000 watts had been used. At the Kino Universum in Berlin, owing to the necessity for economy, not more than 50 per cent of the lighting which the architects originally installed was in use. In the Saville Theatre, London, which I myself designed, for the sake of economy the management have taken out every other lamp and have reduced the wattage of most of the installation. The running cost of a lighting installation is almost more important nowadays than the initial capital outlay. I am driven to the conclusion that the extreme simplicity of much modern architecture arises partly from the general poverty of the world. This is less noticeable in Great Britain than it is in Germany and Austria, which are passing through a much more severe period of depression than we are. This real poverty must result in the development of the highest kind of efficiency both in lighting installation and in architecture. We must therefore carefully consider the merits of the semi-indirect fitting, which circumstances will frequently force upon us. With regard to the Titania Palast in Berlin, mentioned in the paper, several of the lighting coves are either painted or shaded blue, with the result that there is a serious loss of light. I understand that the loss of light caused by certain blue surfaces is more than 75 per cent, and I should like to ask the authors their experience of the loss of light in a lighting cove filled with lamps and painted blue. The question of the reflection of light from wall surfaces is an important one from the point of view of women, who insist upon having satisfactory colours reflected on to their faces. They will not tolerate greens, they do not like yellows, and I have to use a universal shade of rose pink. Lighting engineers tell me that I must place a 100 per cent matt surface behind my lighting coves, but I cannot produce such a surface, although I have tried flat paints, distemper, and other materials. When I do produce a good matt surface my management tell me that it collects too much dust, and that I must revert to a glossy surface. Colour has a very great psychological effect on the occupants of a building. The Germans are trying to introduce yellow into their daylight lamps, because they say that an entirely blue light is unsatisfactory. I find that an indirect lighting scheme for an interior should include some surfaces with a higher intensity of illumination than the general value for the room. With regard to floodlighting, I would inform Prof. Robertson that the lighting system of the Saville Theatre incorporates floodlighting cornices as part of the architecture.

Mr. G. H. Wilson: Most of the modern lighting equipment is installed in cinemas, theatres, and such places as underground railways, where one only sees the lighting effects for a short period at a time; modern equipment has not been widely applied in homes and offices, in which the majority of individuals spend most of their time. In some modern office lighting installations the illumination is very poor indeed, and I think this is frequently due to the fact that an illuminating engineer has not been consulted in connection with the scheme. The responsibility for this is as much the electrical engineer's as the architect's, because the former should make inquiries concerning the amount of power required and the way in which the light should be distributed. Such information is available nowadays, and even if the electrical engineer does not consult a lighting engineer he can refer to the published tables. In the home the lady of the house is often the illuminating engineer, and where the purchase of modern fittings is not possible on account of limited means the result is a function of the artistic sense and the ingenuity of the person concerned. In the home, again, the electrical engineer has responsibility, especially in those cases where assisted wiring is in vogue. In numerous assisted wiring schemes where the engineer supplies the lighting fitting the latter consists of a 9-in. conical opal shade. For a little more expense the electrical engineer can set a good example by supplying something slightly more in keeping with modern ideas. There has recently been a decrease in the overall size of incandescent filament lamps, and this has increased the facility with which lamps can be used in lighting fittings. With regard to opal glass, it is not generally known that totally-enclosing diffusing glasses are obtainable through which the filament of the lamp cannot be seen, but which only absorb 10 per cent or less of the light of the lamp. Quite recently a further large field has been opened up by the development in America of a lamp which emits both light and ultra-violet radiation. It consists of a mercury arc playing between tungsten electrodes, the whole of the system being enclosed in a bulb which absorbs the harmful ultra-violet rays and transmits those considered by some to be beneficial. Installations of these lamps are already being put up in America, if not in this country, and it is stated that the radiation from them is comparable with sunlight.

Mr. H. Long: A paper* published in America in

* *Transactions of the American Illuminating Engineering Society,* 1931 vol. 26, p. 1043.

1931 gave a complete range of utilization factors for certain specific pieces of diffusing glassware boxes, panels, and triangular corner-pieces, among others. There is at present a tendency to substitute large luminous surfaces for the old-fashioned system of decorative lighting by suspended units. Whereas the latter involved a certain amount of scientific calculation, the former disregards science completely and strives only for effect. While I fully appreciate that the architectural effect must take precedence over an artificial lighting scheme, I contend that there is no reason why the light should not be produced in an efficient manner. In modern luminous-panel systems the lamps are just studded behind the glass, and no effort is made to reflect the light efficiently. In other cases the surfaces are coated with white paint, which quickly becomes discoloured on account of the heat. The application of some type of standard reflector seems to me quite possible; in fact, I have had to deal with a number of laylight installations where standard dispersing reflectors have been utilized successfully. Modern advances in heating and lighting have been made on parallel lines. Last session Mr. Grierson* gave us details of the various panel-heating systems, and the present paper deals with panel lighting. The trend seems to be towards large areas of low brightness on the one hand and of low temperature on the other. The rapid development of architectural lighting on the Continent has been assisted not only by the temperament of the population on the other side of the Channel, but also by the fact that their standard of electrical installation is so much lower than our own, and that over there lighting systems can quite easily be installed in a manner which we should regard as only temporary and which would not pass any of our regulations. With regard to gaseous discharge-tube lighting, whilst this is a wonderful decorative medium I think that even if we do obtain white light from it for general illumination purposes there will still be gaps in the spectrum. The incandescent lamp gives a continuous spectrum, whereas the gaseous discharge tube gives a line spectrum, and in cases where colour is important this will matter very considerably, because certain colours will be absent. Turning to the question of the high transmission efficiencies of frosted and sand-blasted glasses, the figures given in the paper are only obtained when these glasses are new, and the majority of such surfaces cannot easily be restored to their pristine efficiency when they are old. According to Mr. Bennett, matt surfaces have the same disadvantage. With regard to the drawback of the upper part of the room being in complete darkness when a totally opaque reflector is used, with this type of lighting system the upper part of the room can be sufficiently well illuminated to avoid a sharp contrast between it and the working plane. The quantity of light thrown up depends on the colour of the work, floors, and desks or other furniture, as well as on the distance between the reflectors and the ceiling. If the reflectors are close to the ceiling the latter is likely to be dark, but matters can be so arranged that it is reasonably well lighted. Conditions can be further improved by using a reflector having apertures in the top, which allow a certain amount of light to travel upwards.

* R. Grierson: "The Electrical Heating of Buildings," *Journal I.E.E.*, 1931, vol. 69, p. 1045.

Mr. H. T. Young: By "efficiency" we really mean "ultimate effectiveness." Engineers have in the past been seeking to get the maximum of light with as small a current consumption as possible, instead of striving for good and pleasing effects. All over the world the expenditure on lighting is now forming a considerable portion of the cost of interior decoration, but it is bringing greater possibilities of true economy than paints and other materials that have to be renewed continually. I do not think, therefore, that the false economy of taking out a few lamps in order to reduce the running costs of lighting installations should discourage us from further progress. Illuminating engineers should co-operate with architects in effecting an improvement in the lighting of public buildings, as this is bound to result in better home lighting. It is more difficult to get improved lighting into the homes than to show people what can be done in places which they frequent day by day. The fact that the industry is making determined efforts to improve hotel lighting up and down the country is bound to have an enormous effect upon the homes of the people. It is important that we should not light our ceilings only, and leave the lower parts of the room in darkness. Besides a light fixed to the ceiling we should have surfaces of low intensity around the walls. Some manufacturers have started to make lamps with a filament which will conform to the contours and angles of rooms. Low-voltage gaseous discharge tubes are not yet available for general lighting, but high-voltage tubes are being used in interiors, and their decorative effect is pleasing. Have these tubes to be shielded by diffusing glass? The illuminating engineer and the architect often judge lighting by the effect on their own eyes, whereas we must provide for the man with very bad sight, and try to make everything that he has to use after dark as cheerful and bright as possible.

[The authors' reply to this discussion will be found on page 112.]

North-Western Centre, at Manchester, 1st November, 1932.

Mr. G. F. Sills: The authors mention people who deplore this mechanical age and regret the disappearance of such lighting appliances as candelabra. This love of age is itself sometimes mechanical, however, and rather in the nature of a fashion. A good lighting system should show up the features the designer has intended to convey, and should balance the colours, giving each its true value. It is unfortunate that the beautiful buildings in London are only seen for 8 hours out of the 24 at this time of the year: the remedy for this is to continue to illuminate them for 24 hours in some cases, and for a shorter period in others.

Mr. A. E. Jepson: It would be interesting to hear the opinions of architects on the views expressed by the

authors. Most architects object to floodlighting from below, on the grounds that the majority of the classic ornaments designed by the Greeks and Romans were intended to be lit from above. I believe that the artistic features of buildings are shown just as well by light coming from below as by light from above. With regard to fenestration, if this follows horizontal lines one obtains a "squashed-down" effect, to which many people have a strong objection. I prefer vertical fenestration, because it conveys the idea of height, which is generally desired in our large buildings. On page 94 reference is made to the output of faked antique lighting fittings. I would prefer to see an increased output of faked antiques rather than of the modernistic fittings installed in many modern private establishments; such fittings are composed of tinted glass and stamped sheet metal, and cannot last above a year or so. Their artistic value is also open to question. The statement (page 94) "Points are now provided, not for 'a light of some sort' but either for a fitting in character with the room or to form a source as a feature of the construction itself," does not fit in with our experience in the North, as we often find that it is only when the building is finished that the architect remembers the electric light: holes then have to be bored through concrete floors and troughs have to be laid for cables. It is not sufficiently realized that very large channels are necessary for laying out a scheme involving complex lighting. The authors' suggestion of using two or three discharge tubes of different colours as a source of light is open to a number of objections, the most serious being the fact that coloured shadows are thrown if the tubes are spaced any appreciable distance apart. I agree that long lines of tube lighting are useful for decorative purposes, and I understand that quite good results are now obtained by placing the coloured tubes behind opal glass panels, the result being almost white light. I should like to refer here to an instructive paper* on the subject of opal glass which was read by J. W. Ryde and Doris E. Yates in 1926. One of the difficulties met with in measuring the amount of discomfort due to glare is the wide divergence between the views of different people. It seems to me that the ones who suffer most discomfort are those with the longest retentivity of vision. Much discomfort can, however, be avoided by the use of Crookes glasses. The answer to the interesting question of why people can work quite as easily when sewing with black material as with white is that while sewing on white material people suffer from the effect of glare, whereas glare is absent when black material is substituted.

Mr. J. Frith: In view of the enormous running cost, the only people who will be able to afford to install the most modern types of lighting equipment will be those connected with cinemas. I know more than one building equipped with an up-to-date lighting installation where the illumination has had to be tremendously curtailed because of the large electricity bills. I am interested in the lighting of the desk at which the office worker sits for so many hours each day, and where it is unfortunately necessary to have artificial light for a great deal of the time. By far the worst type of glare from which he suffers is due to the use of white paper. I am not at all convinced that black on white is the best combination of colours for the purpose of printing. I really believe that many people like a certain amount of glare. The experiment of placing the same lamp in globes of various sizes, giving the same amount of light with varying brightness of the surface of the globe, shows that the less glare there is, the less light one seems to get.

Col. W. S. Beaumont: I think the co-operation of the electrical engineer with the architect should operate from the earliest stages of the planning of a building. After the plan has been completed the architect has to consult all sorts of people to ascertain where they wish to put the particular appliances they are responsible for. With regard to the lighting of large stores, some articles in shops are displayed to greater advantage with indirect lighting, whilst others require a direct light. Materials like silk are not suited to indirect lighting. As the departments in such stores are continually changing, by the time the building is completed the whole distribution of the departments may be different from what it was at the start. This makes it very difficult for the electrical engineer to arrange a scheme for satisfactorily lighting the whole building. The great trouble in connection with shop-window lighting in strong daylight is reflection. I think it is quite possible that shops will have in the future a solid canopy over the footpath, and that the windows will be lit electrically the whole time. The fact that window backs have to be capable of a good many changes in colour introduces the problem of how to cast different shades of colour on one window back without affecting the lighting of the goods. With regard to floodlighting, as a building is seen for more hours in daylight than at night it ought to be designed to please the eye in daylight as well as when floodlighted. Some years ago I visited a house in Brussels in one room of which all the lights were placed behind glass in the cornices, so as to provide the occupant with a bright light wherever he was sitting. Over the mantelpiece there was a very thin sheet of onyx, about 5 ft. square, which gave a delightful effect. The arrangement provided quite enough light for comfort.

Mr. L. Romero: I should like to draw attention to the following sentence on page 95: "It is not in the homes of the rich or highly intellectual that the best decoration or lighting is to be found, but generally in houses and flats occupied by intelligent people whose views on lighting as on other important matters are unprejudiced and progressive." This implies in the first place that neither the rich nor the highly intellectual are intelligent, surely a very doubtful proposition, and secondly that highly intellectual people have less good taste than the merely intelligent. My experience of intellectual people is that they have distinctly better taste than the average. With regard to Mr. Frith's remarks about the excessive cost of improving the lighting of the home, in most districts of this area it is possible to quadruple the lighting load of a house and yet only pay ½d. per unit for the extra consumption.

Mr. J. Sellars: I do not agree with Mr. Jepson's comments respecting the "squashed" appearance of buildings in which horizontal fenestration is adopted. Although a squashed appearance may be obtained by

* "Opal Glasses," *Transactions of the Society of Glass Technology*, 1926, vol. 10.

bad design, horizontal fenestration can give a feeling of spaciousness in a horizontal direction. The question merely is to decide where it should be applied.

Mr. J. S. Beaumont: One of the architect's greatest difficulties in regard to lighting is the fact that even in our homes, where we should like better means of illumination, we are on the average dependent on daylight for 12 hours per day. It is only for perhaps 4 hours in the evening that we require artificial light, and we design our decorations so as to be pleasant during the daytime. The problem for the illuminating engineer is to provide a light for the evening which will be soothing and will tone with the dress worn at that time. The earliest example of floodlighting is to be found in the Parthenon, where the frieze round the *cella* was set by the sculptor at an angle which would enable it to catch the reflected light from the pavement. It established a precedent which is followed by modern floodlighting systems in which the light comes from below rather than from above. Large stores are designed to attract people during the daytime, when customers are most likely to enter them, and we must not, therefore, sacrifice the daytime effect by concentrating too much on the night attraction. Some of the new buildings in Berlin have been designed purely and simply with a view to producing a pleasing lighting effect in the evening, with the result that in daylight they look rather cold and unsympathetic. Spaces should be provided for the mounting of illuminated advertisement plates; this has not always been done in the past. Co-operation between architects and illuminating engineers should take place in the early stages of design, because it is difficult to make changes later when the plans are almost complete. Turning to the question of glare, the colours of our neon tubes and of some of our advertising signs are crude in the extreme. If we can make the outside of our buildings glow rather than glare they will be appreciated far more by the public. In the Roman buildings erected 2 000 years ago openings were made to let in the light, which was then toned down by means of slabs of alabaster.

Mr. E. T. Norris: The artist in lighting has so far given most of his attention to the illumination of such public buildings as cinemas, restaurants, and public offices, a class of lighting which, while often artistic, must essentially be dominant and self-advertising. The authors pay little attention to lighting for purely domestic and æsthetic purposes, which should be less blatant and obtrusive, and might with advantage exploit the exquisite beauty and fascination of shadows. The paper emphasizes the efficiency and effectiveness of lighting designs for various classes of "work." When dealing with the drawing-room (page 96), the authors still have this idea in mind, although here they do suggest a slight shadow effect, not for artistic reasons, but to facilitate needlework. Instead of designing the lighting of the domestic sitting-room from the performance point of view, should not the artist in lighting aim more at actually discouraging work of any kind? In the section dealing with home lighting, little is suggested that is suitable for existing houses. It is impracticable in such cases to carve holes in the wall, or to make the ceiling resemble an inverted Chinese pagoda. The authors emphasize the achievements and capabilities of the artist in lighting when he is allowed plenty of money and given, as far as possible, a free hand. I suggest that he will have achieved a substantial measure of skill in his profession only when he feels able to tackle, both artistically and economically, the sitting-room of an ordinary Council house.

Mr. A. H. Fay: My opinion of the cornice lighting in a London hotel which I visited recently was that it was too glaring. Lighting no doubt exercises an important effect on our moods. The colour of the light is important, because whilst the light may be bright it can also be cold; and conversely, if a suitably coloured shade is adopted, the same light can be made warm and inviting. A bright red colour has important effects on nervous persons. It has been found in many hospitals where nervous cases are being dealt with that patients placed in rooms where red is the predominant colour do not yield to treatment so readily as others placed in rooms where the predominant shades are green or other milder hues. Two good examples of architectural lighting are the cornice scheme at the Memorial Theatre, Stratford-on-Avon, and the Lady Chapel in Hereford Cathedral. The latter is lighted by trough fittings, the front glasses of which are of a diffusing character.

[The authors' reply to this discussion will be found on page 112.]

Scottish Centre, at Glasgow, 8th November, 1932.

Mr. D. M. Macleod: The paper seems to me to be an idealistic treatment of a very practical subject, and as such it tends to stimulate progress in the art of the lighting of buildings. Turning to the question of house lighting, I am afraid that the methods adopted in this field must of necessity be largely governed by the factor of prime cost. In suburban and city areas electricity has still a formidable competitor in gas, an illuminating agent which can be used with equal facility for lighting and heating. Very often, owing to the provision of gas stoves and gas radiators, all that is left to the electrical engineer is the lighting installation of a house, and when this is being planned considerations of cost render it necessary to select stock fittings manufactured by mass-production methods. With regard to the examples of co-ordination between the architect and the illuminating engineer shown by the authors' slides, I should like to know whether Continental architects make it part of their business to study closely the technical side of the lighting problem.

Prof. S. Parker Smith: It is difficult to form a definite opinion about modern lighting schemes. When sitting in buildings where they are installed I have somehow experienced a feeling of discomfort; perhaps it is because I am so used to seeing the source of artificial light, though in Glasgow diffused daylight is quite normal. We shall probably only gradually discover the merits of the new ideas, which represent a transitional stage.

Some of the buildings illustrated by the authors' slides looked as if they had been made to be lit artificially. Do they look equally beautiful by daylight, and are they comfortable to live in?

Mr. E. Seddon: The paper clearly indicates that the end of the point source of light is in sight, and that the future is already mapped out for the opaque glass-box or bar type of lighting system, arranged architecturally to suit the purpose of the particular building. As buildings in the congested areas of our cities become higher, natural light is partly shut off from the lower floors, with the result that the demand for artificial light during the hours of daylight is constantly on the increase. It therefore becomes necessary to design light sources on the most restful lines, by increasing the surface of illumination and effecting a corresponding reduction in the intensity. I believe that in 10 years' time our present system of lighting will appear to be just as antiquated as the old-fashioned carbon lamps with bell shades seem to us to-day. Plenty of restful light helps one to be cheerful and makes life more pleasant for all.

Mr. D. McLennan: With regard to floodlighting, I think that illuminating engineers make a mistake when they use white light for dealing with buildings having fairly dark surfaces. When white light is applied to a black curtain the curtain still appears black; it would clearly be more efficient to flood such buildings with coloured light, in which case a lower intensity would be satisfactory. With regard to the lantern slides exhibited by the authors, I do not know of anyone seriously interested in illumination who would apply such forms of lighting in their own domestic or business premises except for garish purposes. Such systems of lighting are of no interest other than as illustrating a passing phase.

Mr. W. J. Cooper: The authors' reference to the progress made in the production of gaseous discharge lamps at first rather alarmed me, in view of the probable effect on the economics of electricity supply of a sudden introduction of this type of lamp, but I subsequently realized that all would be well if it led to a greatly extended use of electric light for decorative purposes. It is an interesting fact that a modern lighting system may be used as a heating agent, since by far the major portion of the energy dissipated by the electric lamp takes the form of heat. The authors' reference to the psychological effect of good lighting and to its influence on physical fatigue is important. I remember a case where it took 18 months to live down the idea held by work-people that an intense source of light immediately above the work was necessary. There is no doubt that modern lighting, if properly applied, can go a long way towards making people both comfortable and happy.

Mr. H. C. Babb: While I realize the growing importance of treating lighting as an integral part of the architecture of the building, in view of the predominance of the financial aspect consequent upon the present world depression I think that a very useful addition to the paper would have been a comparison of the costs of the various methods of illumination described by the authors. In the rural areas of Scotland many years' work will be required before buildings will be illuminated on the lines described, on account both of initial cost and of averseness to any radical change. A house illuminated in the way indicated in the paper would not lend itself to periodical alterations, and would prevent the owner from expressing his own personality. The authors are somewhat scathing in their criticism of the conventional period finish of some of our great liners. To many this type of decoration gives considerable enjoyment, even if it only serves the purpose of distracting the mind from the sea, which is sometimes very essential. Moreover, it appears to me that the British designer, in incorporating without incongruity an efficient twentieth-century lighting medium in a Jacobean smoking-room, has done something highly commendable. With regard to the use of discharge tubes for obtaining white light, would it be possible to obtain white light by using properly-tinted glass for the tubes, or would the necessary colouring of the glass have to be so deep as to render the tube quite useless as a source of light?

Mr. E. A. Deacon: I should like to refer to the slide shown by the authors which gave a view of the escalator subway of an underground railway in London. The escalator is apparently illuminated by floodlighting from pedestal standards, the light being reflected back from the arched ceiling. As a result, an individual on the escalator has his eyes attracted to the ceiling, where he frequently sees considerable discoloration and numerous large, ugly, blackened cracks. Unless the ceiling is redecorated every few months the lighting effect will be poor, as much of the light will be absorbed by the ceiling. I have in mind a lighting fitting which is more suitable for such a purpose, a fitting, partly of the direct and partly of the semi-indirect type, which is fixed within a few inches of the ceiling. If such a fitting were used the escalator would still be well lit even when the arched ceiling became blackened.

Mr. D. H. Bishop: We engineers are apt to become obsessed with the utilitarian and economic side of our work, and it is therefore hardly to be wondered at that we often lose sight of the artistic and decorative aspect. The paper gives food for the imagination with regard to the possibilities of electric lighting; this is a very good thing in view of the active competition of gas in many branches of service in which electrical engineers would like to take a greater part. The gaseous discharge-tube type of lamp has great possibilities in the field of street lighting, where its high efficiency will give it a big advantage over gas lamps. City authorities will not mind spending as much in the future on street lighting as they are doing now if they can get an increase of 4 to 5 times in the amount of light by electrical methods. I am greatly interested in the authors' numerical measure of the disadvantages due to glare.

[The authors' reply to this discussion will be found on page 112.]

North-Eastern Centre, at Newcastle, 14th November, 1932.

Mr. W. F. T. Pinkney: The spirit of competition which exists in connection with shop lighting and leads to the introduction of new applications of lighting is absent from the sphere of domestic lighting. It is difficult to introduce modern lighting equipment into existing buildings: in newly-built residences, on the other hand, architects are beginning to help by incorporating lighting in their designs. It is necessary at present to preach the necessity of ample light and avoidance of glare. As the intensity of illumination in general use increases, the owners of houses will look round for ways of improving the methods of applying illumination. The majority of those better-class residences which were wired for electric lighting 20 to 30 years ago still retain their original installations. Few residences to-day are without opal conical shades, and few have more than one lighting position per room. I doubt whether 1 per cent have ample light for normal domestic requirements. The type of lighting described by the authors, which is part of the decorative scheme and architectural design of the house, has come to stay. Although tubular lighting by means of a tungsten filament can be adapted to suit existing domestic architecture without the necessity for structural alteration, the ultimate development of domestic lighting will probably be in the direction of large luminous areas applied with due regard to the architectural features of the room, and with the addition of decorative lights giving points of emphasis where these are required for purely æsthetic purposes. There should be a wide field, in connection with electric lighting, for the employment of women with some training in art, in architecture, and subsequently in illumination. The future of gaseous tube lighting is a little doubtful; I think that its use will be confined mainly to advertising, and that for this purpose it is rather a fashion of the moment. In my opinion floodlighting has a far greater future, but there is much room for improvement in its application. The value of shadows in floodlighting has seldom been recognized, and the application of floodlighting has been too exact. The uniform illumination adopted has created unnecessary artificiality. Another system of lighting which will probably grow in popularity consists in the use of compensated ultra-violet rays, i.e. ultra-violet rays mixed with rays of ordinary light, the mixture being distributed from silica bowls. This method of illumination has been found to have very advantageous results in places into which little daylight is able to penetrate. Except where the light source is in the direct line of vision, glare is not met with to any extent in ordinary lighting practice, as the present standard of illumination is too low to create glare unless the illumination is wrongly applied. If it is wrongly applied, both "disability" glare and "discomfort" glare will be present. In street lighting, however, where the contrasts are too great "disability" glare is a very real danger, and is difficult to avoid. The remedy lies in the use of a standard of illumination equal to that which is now provided in Piccadilly, London, where the intensity of illumination and the distribution of light are such that the contrasts within the normal field of vision are greatly reduced. Under such conditions "discomfort" glare may be met with, but it is not of great importance, and "disability" glare is practically absent. The subject of colour in lighting is a very interesting one. Quite apart from the practical application of daylight lighting for colour matching, colour lighting has a very definite effect upon the feelings, and even upon the mentality. Great comfort can be secured by the use of colour lighting in the home, provided that as high an intensity of illumination is maintained as is given by an ordinary lighting system.

Mr. L. C. Grant: The efficiency of lighting equipment, i.e. the ratio of the light emitted by the lighting unit to the light produced by the lamp, is sometimes ignored. Fittings which waste 80 to 90 per cent of the light emitted by the lamp are not uncommon, while for the better-quality lighting equipment an efficiency of 50 per cent is usually considered to be good. Coupled with efficiency is the problem of avoiding glare. The gas-filled lamp has a filament intensity of several thousand foot-candles, far too high a value for the human eye to receive safely. An attempt has recently been made to design glare-free lighting apparatus of reasonably high efficiency. Some of this apparatus has been installed in the new Dunston power station. To obtain a high transmission efficiency, a number of tests were carried out on diffusing glasses. One specimen was obtained with a regular transmission factor of 65 per cent, and later another became available with 75 to 80 per cent transmission. This glass was used as the basis of the designs. The fact that the internal efficiency of the lighting apparatus may be as low as 10 per cent is very important. The lumen output of a given lantern was increased to 3 times its original value by using a mirror-glass lining of suitable surface and colour in place of the bright metal reflectors previously employed. The outcome of these experiments was lighting equipment of 80 per cent total efficiency, with a maximum intrinsic brilliancy of 500 foot-candles, which was decided upon after photometer tests in daylight and bright artificial light. Sunlight may produce a brilliancy of as much as 25 000 foot-candles, and in the North of England 8 000 foot-candles has been measured. Both figures are too high for the eye for prolonged use: 3 000 foot-candles seems to be about the upper limit, and only 2 000 foot-candles can be tolerated by many people. In order to obtain a margin, however, the value of 500 foot-candles was adopted. The appearance of the light sources is restful and quite innocuous. They have the further advantage that, owing to the absence of glare, they enhance the seeing power of the eye with a given working-plane intensity. Working intensities of 5 to 15 foot-candles were adopted in place of the common figure of 1 to 2 foot-candles, which are economical of electricity but extravagant of eyesight. As the daylight intensity inside a building may be several hundred foot-candles, 10 foot-candles for artificial lighting is wasteful neither of light nor of current. An equipment capable of giving an intensity of 70 foot-candles without glare has also been put into use and has been found in practice to produce a

remarkably good effect, and to reduce the strain of seeing in artificial light.

Mr. G. N. Peel: In the Introduction the authors say that not many years ago the illuminating engineer's principal aim was to provide as much light as possible, and to distribute this light as advantageously as he could; later in the same paragraph they remark that happily all this is now changed, thanks to the enormous progress which has been made. These statements draw attention to the fact that a distribution of light which is satisfactory in the æsthetic sense is not necessarily advantageous in the economic sense. For example, a 100-watt lamp placed in a bowl in a room 20 ft. by 15 ft. does, at any rate, illuminate the room; whereas to provide an artistic lighting effect with panels in the ceiling it would probably be necessary to have an input of 1 kW. Such a loading is not at present economical for people of ordinary means, and according to the authors these are the very people who most appreciate good lighting. During recent years experiments have been made with a view to the discovery of sources of illumination which emit a proportion of ultra-violet light, the idea being to introduce artificial sunlight into rooms which normally receive little or no natural light. Have these experiments been successful?

[The authors' reply to this discussion will be found on page 112.]

South Midland Centre, at Birmingham, 21st November, 1932.

Prof. W. Cramp: No new building can be intrinsically beautiful, but it can be serviceable, dignified, restrained, and even natural. If it expresses the service for which it is intended, it will automatically become beautiful. Hitherto, architects have designed their buildings from the outside inwards, instead of from the inside outwards. This statement applies whether it is considered either metaphysically or from the point of view of actual practice. Architects aim at creating beauty; they often achieve only extravagance, uselessness, and artificiality. The same is true of lighting: if the aim is service, not effect, beauty will follow. There are two examples of public lighting in Birmingham which illustrate these aphorisms. In the first the gas engineers, who were given a free hand, produced a tremendous intensity of illumination, resulting in an ostentatious display with glare as its chief feature. In the second example an architect was given a free hand, and he produced a road where everything is subordinated to artistic pedantry, without reference to the principles of scientific illumination. In general, the troubles met with in connection with modern lighting arise from the fact that the architect handles the lighting specification and regards it only as an adjunct to the building, instead of as an essential part. Of the principles of modern wiring he is, as a rule, ill-informed, though nowadays most architects do at least make provision for conduits and wires. Of the modern principles of scientific illumination he is generally ignorant, so that it is not unusual to find a completely-finished building for which the electric light fittings have not even been selected. No remedy for this state of affairs will be possible until either an illuminating specialist is allowed to dictate to the architect before the building is erected, or (as abroad) architects themselves are trained to have a knowledge of, and respect for, lighting effects and technique.

Mr. T. A. Margary: I would suggest to the authors that when buildings, particularly those to be used as places of public entertainment, are being designed, a psychologist should be called in to advise the architect and the lighting engineer, who are rather apt to overlook the effect the finished scheme will have on the public. In a number of modern buildings which I have seen, where attempts have been made to co-ordinate the work of the lighting engineer and the architect, the lighting is scientifically perfect, yet the effect is depressing. Extensive use is made of concealed lighting, with the result that the illumination is too uniform and there are no outstanding bright points upon which to focus the eye. In my opinion the best effect would be obtained by the use of partly-concealed lighting together with fittings hung or supported some distance away from the walls or ceiling. This system would introduce the effect of movement, because as one walked in or out of the building the position of the fittings relative to the walls would appear to change. Some 25 years ago a West End hotel famous for its dancing floor had its dining-room lit by concealed lighting (then called cornice lighting). Although the illumination in the dining-room was perfect the effect was depressing, and for this reason the proprietors lost a good deal of business, as a large number of the younger dancers formed the habit of dining at a cheerful but unscientifically-lighted Italian restaurant a few doors away. Had there been in addition to the cornice lighting a few bright fittings in the hotel dining-room, the room would have been quite cheerful. The objection I see to making the lighting scheme part of the structure of a building is that it cannot be changed without making extensive alterations, and, in consequence, the lighting system originally installed will in all probability have to remain throughout the life of the building. This is a serious disadvantage, as it is well worth while for a theatre, cinema, or other place of public resort, to change both its colour scheme and its lighting system from time to time, and the more cheaply this can be done the more frequently will such a change be made.

Mr. L. Leech: It is improbable that the styles shown in the authors' slides would lend themselves to home lighting, but they serve to prepare the public and make it receptive to new forms of fittings. The general public will be the ultimate judge of any system in which taste is combined with utility. To become popular a new style must be an advance on the old, but it must not be too far removed from the present accepted forms, particularly if it is for use in dwelling-house systems. The modern style of public building certainly fulfils these conditions. The interiors of cinemas shown in the authors' slides had simple and pleasing lines. The harmonious whole could be instantly appreciated, an

essential feature in this class of illumination, where the effect is only a support for the entertainment proper and, in consequence, only short periods of time are allowable for the effect to be registered. The authors call attention to the large, well-illuminated, plane surfaces left on the outside of cinemas for displaying advertising matter. The simple lines of the modern style of building do not limit the space which can be used for this purpose without producing an adverse effect on the general appearance. Sign manufacturers have still something to learn from show-card writers about the artistic form which can be expressed in the 26 letters of the alphabet without adversely affecting their clarity. In the examples of home lighting shown by the authors, some of the points were mounted low down on the sides of the furniture. Has the danger to which children may be subjected by this practice been considered?

Mr. J. A. Sumner: Are the authors suggesting any criterion for modern lighting? The lantern slides appear to emphasize lighting from the roof, which I consider to be unnatural and harmful to the eyes. In equatorial countries where the sun is immediately overhead it is necessary to adopt a means of shading the eyes. The authors' formula for glare seems to show that the minimum glare, and probably the best psychological effect, would be produced by lighting from the floor. I know of an instance where a living-room, 19 ft. × 13 ft. and 9 ft. 6 in. high, was lighted by five 60-watt lamps on the walls and by four 100-watt lamps in the ceiling, two of these being placed in each of two holes in the ceiling; alabaster bowls are used to shade the naked lamps. Observers considered this room when fully lighted (nearly 700 watts) to be rather dull. This was apparently due to the fact that it was a combination of indirect and diffused lighting with no obvious sources of light. When lamps totalling 300 watts were switched on, the room appeared to be fairly well lighted, whereas the effect of switching on the remainder did not have a proportionate effect in increasing the illumination.

[The authors' reply to this discussion will be found on page 112.]

Mersey and North Wales (Liverpool) Centre, at Liverpool, 5th December, 1932.

Mr. O. C. Waygood: The authors stress the point that lighting should become an architectural feature of the building: although I subscribe to this view in theory, the maintenance costs of architectural lighting are prohibitive owing to the high cost of the unit of electricity. To reveal an architectural feature by means of lighting, and at the same time to illuminate the building, involves a recurring charge on the capital outlay. Architectural effects and illumination must be kept distinct, as the light required for the former may not suffice for general illumination. It may be cheaper to use paint rather than electricity for colour or decorative schemes in buildings. With regard to shop lighting, in the illumination of a large store one has to deal with merchandise of varying hues and substance. The minimum number of fittings should be used, and means should be provided whereby direct lighting, indirect lighting, or a combination of both, may be employed at will. Will the authors give some indication as to the intensities of light which should be adopted in practice? The values suggested by the Electric Light Manufacturers' Association are rather high, and involve heavy maintenance costs. The Institution can do a great deal to foster and encourage the spirit of co-operation between architects and electrical engineers, and the paper will help in this respect.

Mr. R. A. Harrison-Watson: I do not think we shall be successful in persuading people to adopt panel lighting, mainly because ladies prefer the lighting equipment of a room to be movable. While totally indirect lighting is suitable for offices, it is subject to a loss of efficiency through the reflectors and ceilings getting dirty. For home lighting it is not generally liked, owing to the absence of shadow and the loss of colour effect. It would have been interesting to have had some information regarding the lighting distribution in large commercial office buildings. The lighting problem in theatres, cinemas, and shops, is largely a matter of advertising and decorative effect. What the installation engineer has to do is to bring the light to the point where the architect wants it, and success depends upon co-operation between the architect and the engineer. I should be glad of further particulars of the gaseous discharge tube: is this being developed with the idea of applying it to ordinary building illumination?

Mr. R. Eastman: The authors give no details of initial and maintenance costs, a very important aspect of lighting. Further, they do not explain the construction of the panel lighting units. Is an interior white surface employed for their beam lighting, or are properly designed reflectors used? What is the size of lamp employed, and what is the loading in watts per sq. ft.? I favour the modern tendency to revert to indirect lighting, which, since the introduction of gas-filled lamps, more efficient reflectors, and lower prices for current, has gained many advantages over other methods. A good deal of the modern beam lighting is extravagant, from the point of view of current consumption, besides being fairly expensive to install. The floor-standard type of fitting may be used to combine both attractiveness and efficiency, as it can be designed to give indirect lighting for the general illumination of the room and minor illumination for the decoration of the fitting itself. Turning to the question of co-operation between the architect and the electrical engineer, until comparatively recently the artificial lighting equipment of a new building was always left until the last and treated as a very minor matter. Usually too small a sum is allowed to provide a reasonable lighting installation in comparison with the sum spent on the rest of the building.

Mr. L. Barnish: Electric light is the most expensive form of decoration for a building, and in its full scope it must be limited to buildings such as cinemas and restaurants, which are used only for 3 or 4 hours daily. Purely for reasons of economy, a great many houses will always depend on a naked light. The authors rather

deride Victorian architecture; although every modern architect will agree that much of the Victorian decoration was bad, I feel that certain traditional forms will live for ever. After a space of time we shall probably tire of the simple, plain buildings and revert to rich carving and colour, adequately lighted.

The Authors' Reply to the Discussions at London, Manchester, Glasgow, Newcastle, Birmingham, and Liverpool.

Mr. A. B. Read and **Dr. J. W. T. Walsh** (*in reply*): The cost of modern lighting schemes for public buildings, and especially for places of entertainment, is not disproportionate to the other costs involved in furnishing and in decoration. Speakers have inferred that many of the lighting features which we illustrated are extravagant and unnecessary, and it has been assumed that interesting modern lighting by electricity is possible only for millionaires. It is, however, becoming more obvious every day that lighting is the greatest factor in interior decoration; and where real thought has been given to it, directed by good taste, lighting schemes have not been unduly expensive and have justified the fair proportion of available funds spent on them.

Experiment has been criticized by traditionalists at several Local Centres, and hopes have been expressed that there may be a return to the charm, richness, and comfort of traditional homes, free from the fearfulness of modern lighting. One architect hopes to see buildings with "rich carving and colour, adequately lighted," but states that, in most homes, naked lights are used from sheer necessity. These ideas are not, however, an expression of progressive architectural thought to-day, and while extraneous and unnecessary richness and decoration have disappeared from sensibly-designed modern homes, a small proportion of the money thus saved has provided a flashed-opal dustproof cover for many a naked light. The homes of the world will be influenced more and more by the introduction of new materials, and the operation of the household will be changed in the future by new forms of energy. Utility and comfort are best served where the new elements are introduced discriminately and harmoniously, and lighting must take its proportionate place. The experiments that are being made in public buildings will certainly affect lighting in the home. There is no finality about the form which this lighting will take; for even the source of light may be superseded, as, for example, by the gaseous discharge tube.

This is, unfortunately in some respects, an age of specialists, and even appreciation of appropriate form and colour is confined to comparatively few. A more general education in which the illuminating engineer is provided with a reasonable standard of taste, and the architect with the power to discriminate between architecture and archaeology, might produce a happier combination of real efficiency and effectiveness. This perfect co-operation is not often achieved, but there is certainly a growing number of well-designed buildings adequately lighted at reasonable cost.

Several speakers have referred to the problems connected with the use of gaseous discharge tubes for general lighting purposes. While it is true, as Mr. Paterson says, that colour effects disappear at low-illumination levels, it is to be hoped that the use of such low illuminations will not be contemplated for ordinary purposes, but that some other means will be found for overcoming the difficulty. The intensive research now in progress may result in the production of a tube giving light of a more satisfactory spectral distribution, or else it may be found necessary to use two or more tubes of different kinds side by side so as to produce a mixture of light rays which is a satisfactory imitation of a "white" light. The use of coloured glass in order to produce a satisfactory white, as suggested by Mr. Babb, does not seem to be practicable with the tubes at present available.

The psychological effect of any pronounced colour in a lighting system has been touched upon by several speakers. It is a matter on which very little experimental work has been carried out, and, as is perhaps to be expected, opinions differ widely.

The loss of light after reflection from coloured surfaces is, as Mr. Bennett has pointed out, serious, especially in the case of blue or violet surfaces, because ordinary artificial light contains few blue rays. The solution would seem to lie in the use of a source (such as a gaseous discharge tube) giving most of its light at the blue end of the spectrum. The only way to maintain a high reflection factor with matt surfaces is to renew them frequently. The reflecting properties of wall and ceiling materials must be carefully considered when any attempt is made to use an indirect or semi-indirect system of the "dual-purpose" lighting (combination of light and ultra-violet radiation) referred to by Mr. Wilson and Mr. Pinkney. Mr. McLennan suggests that it would be more economical to flood dark buildings with coloured light than with white light. It is difficult to see why the loss of light at the building face should be less under these conditions, and, moreover, there is the inevitable loss involved in producing coloured light from ordinary sources.

Several speakers have referred to the loss of light in opal-glass fittings. It does not appear to be generally known that during the last few years enormous advances have been made in the manufacture of this type of glass, and to-day it is quite easy to obtain glass of British manufacture such that the efficiency of a totally enclosed fitting is well over 80 per cent. This result has largely come about owing to the present excellent understanding between glass-makers and illuminating engineers, in no small measure due to the work of the British Standards Institution.

The fittings referred to by Mr. Grant have an efficiency of 75 to 80 per cent, with a maximum brightness of 500 equivalent foot-candles (i.e. about 1·2 candles per sq. in.). This is considerably below the limit of 5 candles per sq. in. prescribed in the British Standard Specification for Translucent Glassware Illumination Fittings for Interior Lighting (No. 324—1928), and the fact that this low brightness is attained at such a comparatively slight sacrifice of light must be considered to be very satisfactory.

ELECTRICAL PLANT AND MACHINERY.*

By J. HARCOURT WILLIAMS, Member.

During the period under review, namely October 1929 to September 1932, contrary to what has taken place in many other countries, the consumption of electricity in Great Britain has increased. It cannot, however, be said that this increase has been accompanied by any very marked development, either of new types of machines or of new plant. This is doubtless attributable to the depression in industries as a whole throughout the world, and particularly in the basic ones in this country. When such a condition exists it is seldom possible, on economic grounds, for either the prospective user or the manufacturer to incur the expense which new developments usually entail.

The greatest progress has probably been in the direction of improving existing designs, such as by obtaining a greater output from machines of a given weight, and by enabling increased economies to be effected in works production. Much has also been done in finding new applications for existing apparatus.

Taking all the circumstances into consideration, progress has, nevertheless, been satisfactory on the whole.

TRANSFORMERS.

The size of transformers built in Great Britain has continued to increase, owing to skilful and ingenious design on the part of the manufacturers. This has taken place in spite of the limits imposed by considerations of transport and the railway loading gauge. The railways now have special vehicles capable of transporting loads up to 150 tons, and road vehicles can deal with 100-ton weights.

This growth is particularly noticeable in the case of 3-phase transformers for large capacities, which have found more favour in this country and on the Continent than the single-phase type. There is a saving in cost and in space occupied, and less cable is required. There is now a tendency in America, where, in the past, single-phase units have been preferred, also to follow this practice. In certain instances the above limitations have necessitated the use of single-phase transformers in order to obtain the desired capacity.

Except in the centre of large towns, transformers are, where possible, usually located in the open air in order to save the cost of buildings.

The general practice with large power-station step-up transformers is to use forced oil-cooling with separate coolers. Large transformers can be built at a somewhat lower cost with internal water-cooling coils. This type of cooling is popular in America, but has not found favour in England, where there appears to be a preference for keeping the water-cooling equipment entirely outside the transformer. With forced oil-cooling, the oil pressure is greater than that of the cooling water. This prevents the leakage of water into the oil, and is probably the reason for the preference. Experience shows, however, that there is little risk of leakage in the water-cooling pipes, and they can be effectively cleaned when necessary.

For large substation transformers the established practice is still to use naturally-cooled transformers for ratings up to 30 000 kVA, and for ratings above this to obtain the additional cooling by means of air blast or air jets on to the radiators provided on the tank for the naturally-cooled rating. In such units with mixed cooling, the naturally-cooled rating is from 50 to 70 per cent of the artificially-cooled rating, depending on the ratio of the copper losses to the iron losses. Generally speaking, this method of cooling is applicable when the load factor is 75 per cent or less.

It is now common practice for transformers for this country to be shipped complete in oil, dried out and ready for service, so that no further drying-out is necessary on site. The transport facilities available in Great Britain enable this to be accomplished even with the very large units.

For abroad, transformers have generally to be shipped without oil, owing to the restrictions imposed by the shipping companies. In such circumstances, the transformers are shipped dry in their tanks, with the air in the tank either under a slight pressure or a slight vacuum. Both of these methods have given satisfactory results, and transformers have arrived at all parts of the world dry, ready for filling with oil and putting into service.

In the construction of transformers there has been little change, except that pressboard is taking the place of bakelized paper, and is now available in the form of built-up cylinders suitable for the main insulation on large transformers. Where transport to site can be made with the transformer oil-filled, this method of insulation is very satisfactory; but for shipments abroad out of oil, cylinders of synthetic resin-treated paper are still considered preferable.

The quality of sheet steel has not been improved, but the present highest quality of steel permits of designs having a low core loss and a high efficiency, these requirements often being imposed owing to the capital value of the annual losses.

For the windings, paper insulation on the conductors is now practically universal, even down to the smallest size of wire. Shrinkage of the windings and of the insulation is mitigated by seasoning the windings in the factory, and they are often varnish-dipped to increase their solidity. This is necessary with small wires, but with medium-size and large transformers some makers achieve equally good results, so far as the strength and solidity of the winding are concerned, without varnish-

* A review of progress.

dipping, the paper-insulated conductors being impregnated directly with insulating oil.

As regards the general structure of transformers, profile iron and welded sheet-steel structures are employed, and castings have practically disappeared. The welded construction is lighter, cheaper, and cleaner.

Terminal bushings can be satisfactorily obtained in porcelain up to about 50 kV, above which voltage either the condenser type or the oil-filled type is used. Both the latter types are satisfactory and cost about the same, although the oil-filled bushing has generally a larger diameter, which makes it more difficult of accommodation on small extra-high-voltage units.

The provision of an oil conservator is general for outdoor transformers, and also for indoor transformers in humid climates. The latest development is the fitting of an S pipe connection, between the conservator and the transformer tank, thus preventing free interchange of oil under static conditions and further mitigating the tendency to sludge.

Breathers for fitting to the oil conservator are either of the calcium-chloride type with the calcium chloride contained in trays, or of the box type filled with silica gel. The latter can be reconditioned and can also be designed to change colour when saturated, thereby giving a visual indication that reconditioning is required.

In the direction of standardization, the interturn insulation of transformer windings is now the subject of a British Standard Specification (No. 422–1931), this being the first of its kind dealing with the matter. It is interesting to note that the requirements of this Specification are correlated with those for the insulation and strength of the bushings and line insulators as provided for in previous Standard Specifications (No. 137—1930, and No. 223—1931).

The endeavours to obtain some measure of standardization for the smaller types of transformers would now appear to be meeting with some success, and already one association whose members have considerable interests in rural distribution has produced, in conjunction and agreement with the manufacturers, a specification with the object of standardizing voltages, tappings, mechanical design, and location of parts, etc. This specification does not deal in any way with materials or methods of construction, which are left to the appropriate British Standard Specification.

In some cases transformers of somewhat special design have been manufactured to meet certain conditions, an instance of which is the use of a transformer of 20 000-kVA capacity with three circuits, two of these rated at 15 000 kVA connecting two systems together at 132 kV, while securing metallic separation, and the third winding of 5 000 kVA being required to give a local supply.

For use in street boxes or places where excessive moisture or flooding may occur and where breathing may cause condensation inside the transformer, a non-breathing type of transformer is now available. The top of the tank is fitted with an expansion vessel connected at its centre to the top of the transformer tank and located just above it. This chamber is constructed of two flat, corrugated, copper discs joined together at the edges and left free to expand outwards from each other at the centre. The centre connection to the tank lid serves both as a support for the diaphragm and as an oil-connecting pipe between it and the transformer tank proper. Vertical guide-rods fixed to the top of the tank support the device horizontally. Expansion of the oil due to the warming-up of the transformer is taken care of by distension of the diaphragm.

Single-phase potential transformers of the outdoor oil-immersed type have now been built, suitable for direct connection to high-voltage lines (up to 132 kV) without the necessity of any protective switchgear or fuses. They are of the static, shielded, surge-proof type, and are so designed as to ensure that transient over-voltages and switching surges will be uniformly distributed throughout the windings and not concentrated on the end turns.

There are also a few small (50 kVA) single-phase auxiliary transformers in use, stepping down from 132 kV to 400 V for power and lighting in substations. The smallest 3-phase units so far built for use on the 132-kV national system are rated at 3 000 kVA, and it is considered that even smaller units could be economically constructed if desired.

Transformers for use with electric furnaces up to 40 000 amperes, and for use with mercury-arc rectifiers up to 5 000 kW, have been built in this country.

Disturbances on High-Voltage Systems.

On large high-voltage transmission systems, where a number of large transformers are permanently connected at different points of distribution, the voltage wave-form is likely to become distorted at light loads, and also, under certain conditions, during periods of full load. This is due to the fact that, although the third harmonic introduced by the distorted wave of magnetizing current (which depends on the degree of saturation of the iron core) required by a transformer to give a sine wave of voltage is usually absorbed in the delta or tertiary winding, the fifth harmonic (which is the next largest to the third) cannot circulate in this way and must pass into the system. This condition is affected by the ratio of the capacity of the running generating plant to that of the transformers connected to the system; and at times of light load, when the capacity of the generators connected is relatively small, an increased voltage harmonic is required in order to circulate the necessary harmonic of the magnetizing current; this, in turn, affects the wave-form of the whole system. In large transmission systems the effect of the capacity current produced by the distorted wave often accentuates the distortion still further.

In order to remove the disadvantages brought about by this effect and to improve the wave-form of the system, harmonic absorbers have been designed. Two different types are now available—one a static device, and the other a rotary synchronous machine.

The static equipment consists of a transformer supplying static condensers, with an automatic regulating resistance and control gear, the whole forming a 3-phase resonant circuit. The adjustment is made by means of a voltmeter on the control panel, the instrument responding only to the 250-cycle component of the system voltage.

The rotary harmonic absorber is arranged for connection to the low-voltage side of the system (e.g. at 6·6 kV)

from which it operates as a synchronous motor, the windings being arranged so that 250-cycle current is drawn from the system, with control by a field rheostat. The stator of this machine is arranged so that it may be rotated, thus ensuring that the fifth-harmonic current is absorbed in the correct phase relative to the fundamental; and control is carried out by means of a voltmeter in a similar manner to that adopted for the static machine.

Noise.

Much attention has recently been given to the elimination of noise in electrical machines. The sound normally emitted by apparatus is not necessarily objectionable, but in many instances it may become so in certain locations such as residential areas, particularly during the night time when the majority of noises, such as that due to traffic, have ceased. The tendency in many instances to locate transformers out of doors increases the importance of quiet running. The chief offenders in the past have been transformers and high-speed rotating machinery.

Very careful and thorough research has been carried out on this subject by several investigators. This has necessitated study of the noises emitted. One method is to use a microphone and cathode-ray oscillograph, and to filter out each component of frequency and compare it with a standard source of noise. Thus the investigations have been on the lines of eliminating the cause, rather than confining the noise within special enclosures.

The result has been that with properly designed machines there is now little likelihood of serious trouble arising on this account. Transformers are now designed with low magnetic flux densities, so as to eliminate undesirable harmonics, and special attention is given to all structural parts, with the object of making this type of machine quiet in operation. In rotating machinery, attention has been given to the design of brush gear and of parts affected by the windage of the machine, such as commutator risers.

Fire Risk.

The possibility of oil fires occurring in connection with transformers, particularly where the latter are installed inside buildings, has received some consideration during the last year or two. Such fires are, however, of rare occurrence, and when the number of transformers now operating is taken into consideration the percentage of fires is extremely small. Where they have occurred there have sometimes been contributory causes outside the transformer itself to account for them.

Protection against fire usually takes the form of apparatus arranged to discharge automatically an inert gas under pressure inside the transformer chamber. This is effective and causes little or no damage to the electrical equipment itself. Precautions have to be taken to prevent persons being injuriously affected by the gas, but with ordinary care there is little or no risk of this.

Voltage Regulation.

The linking-up of large systems which is now taking place, together with the growth of a.c. networks and the necessity of keeping the voltage variation of these within the statutory limits, has brought about an extended employment of voltage-control apparatus. Further, the desire adequately to load up distributors has led to an increasing use of such appliances.

This matter has also become of much greater importance since the use of heating and cooking apparatus has increased, both for domestic and for commercial uses. The need for voltage regulation exists both in heavily loaded urban and suburban areas and in rural districts, where the distributors are often very long and where there is usually a large number of small transformers connected to the circuit.

Tap-changing gear, for the purpose of controlling the voltage of transmission lines and the transfer of power on system interconnectors, is already well established. Off-circuit tapping switches are available and can be fitted to transformers of almost any size and voltage. On-load tap-changing gear has now become very common in Great Britain and is available for hand, remote-controlled, semi-automatic, or fully automatic, operation. This latter apparatus is now so designed that at the time when a transformer is switched into parallel with another unit already on load the tap-changing gear automatically runs until its tap corresponds to that of the transformer already in service.

Standard gear for this purpose is obtainable up to 66 kV and 1 200 amperes. It is also applicable to transformers for higher voltages, in which case the tappings are fitted at the neutral end of a star-connected winding, the voltages between the tappings and earth being thus limited.

The prevalence of on-load tap-changers has also been a factor in the use of 3-phase transformers instead of three single-phase transformers in a bank. On the 3-phase transformers only one operating mechanism is required for the 3-phase switch, whereas on the three single-phase transformers one operating mechanism and tap switch are required on each transformer, and the three switches have to be mechanically coupled up to the motor driving-gear.

The general tendency of design is for such gear to be made self-contained and to be fitted on the side of the tank. Previously the tapping selector switches were placed in the transformer tank and the change-over switches outside. This arrangement generally led to a more bulky transformer and the gear was less accessible for inspection.

The main difficulties in providing voltage-regulating gear for small transformers are the cost and the extra space required to accommodate such apparatus.

For these reasons tap-changing devices as used on the larger transformers are not applicable to smaller sizes, and other methods have been developed, with the object of providing suitable voltage control, either by simpler apparatus mounted on the transformer tank itself or by self-contained voltage regulators used in conjunction with appropriate transformers. An example of the first type takes the form of an oil-immersed drum controller, either hand- or motor-operated. The various tappings of the transformer are connected to the controller fingers, the usual reactance being provided for use when passing from one tap to another.

Another type embodies mercury switches for tap-changing, these consisting of glass tubes containing mercury in the presence of an inert gas, which has the effect of preventing pitting or burning. The switch functions by being tilted about one end. In both these methods the apparatus is mounted on, and forms part of, the top or side of the tank of the transformer to be regulated.

Several designs of small self-contained regulators are now available for the control of voltage; in the moving-coil regulator the primary winding is in two sections, spaced apart. Between these there are two series coils inductively coupled with them. In the intervening space is located a movable, short-circuited coil which, when situated in the mid-position between the coils, is neutral, whereas by moving this coil towards one or other of the sets of coils the voltage in the circuit controlled is raised or lowered. There are no moving contacts or flexible connections in this type of regulator.

Another form consists of a stator with both primary and secondary windings on it, and a laminated rotor equivalent to a short-circuited winding, so that in this case also no flexible connections or slip-rings are required.

In the neutral position of this polyphase regulator the voltage induced in the secondary is zero, and there is therefore no phase angle. When, however, the rotor is moved from this position the magnetic flux cuts the secondary winding, causing a raising or lowering (as required) of the secondary voltage, depending on the direction of rotation.

Another method is to use some form of automatic boosting arrangement which will increase the voltage as the load rises, or, alternatively, maintain it at all loads if the supply voltage falls.

A device known as a pressure controller is now made, employing either an auto-connected or a double winding having two reactances connected between one of the secondary terminals and a tapping of the transformer winding, the centre point between the two reactances constituting the outgoing terminal at the end of the winding.

Under no-load conditions these reactances act as a potential divider, and their characteristics are such that the desired secondary voltage is obtained at the outgoing terminals of the apparatus. The one connected to the end of the winding has a closed iron circuit which is practically saturated; the other, connected to the tapping, is constructed with an air-gap in its core, and the voltage across it is proportional to the load. When a load of approximately unity power factor is imposed there is a considerable phase angle between the load-voltage and the inductance voltage. This results in an increase in the secondary line voltage as the load increases. This type of apparatus is suitable for circuits of approximately unity power factor.

A self-compounded distribution transformer has now been produced which has a voltage characteristic rising with the load, and which is available in ratings such as are usually required for rural distribution. Such a transformer can be used as long as the power factor of the load is not less than 0·95 lagging at full load, that is to say, where the motor load is not more than about one-half of the combined lighting, cooking, and heating load. It may be noted that with a 30 per cent industrial load at 0·8 power factor and a 70 per cent domestic load at unity power factor, the resultant power factor on the system would be 0·98 lagging. This type of transformer will give a voltage-rise of 2 per cent at full load, with a constant value of the supply voltage, as against a drop of 3 per cent on a normal transformer; and a full-load efficiency rather less than for a standard transformer, but comparable with that of a combination of a transformer and a voltage regulator.

One of the better-known methods of obtaining voltage regulation is the induction regulator. Although long established, in both large and small sizes, its use has very much increased, particularly in connection with bulk supplies, low-voltage distribution networks (employing quite small units), and power station interconnectors. It is also used in conjunction with the control of rectifiers.

Regulators of 2 150 kVA controlling loads of 20 000 kVA have now been constructed. Simultaneous control of several regulators from one voltage relay is now possible, so that the angular position of all rotors is kept in step.

Regulated feeders operating in parallel can be automatically controlled, so that equal or proportionate loads are maintained.

Mercury Rectifiers.

There has been a marked increase in the employment of mercury rectifiers in this country, particularly for traction supplies to railways; and had there been any material growth in the demand for d.c. supplies, many convertors of this type might have been installed to meet it, in spite of their somewhat low efficiency at normal d.c. distribution voltages. Machines of the metal vacuum-chamber type, having a rating of 2 000 kW at 600 volts and 1 500 kW at 1 500 volts, are now running successfully.

The difficulties experienced in the early types of steel-tank rectifiers have now been overcome by improved methods of welding and sealing the vacuum chamber and by the use of more efficient vacuum pumps.

The starting of cold rectifiers and their immediate subjection to heavy loads, without the necessity of previous heating and consequent delay, are now possible as a result of improvements in the anode shield.

The introduction of grid control has led to more accurate control of the arc discharge. This has resulted in better voltage regulation and in the prevention, to a large extent, of troubles from backfiring. Grid control opens up the possibility of using this form of apparatus for the conversion of direct current to alternating current, and also for transferring power from one frequency to another.

The glass-bulb mercury rectifier has now entered the field of railway electrification, and its working capacity has been considerably increased. Individual glass bulbs are available having a rating of 400 amperes at 550 volts, or 500 amperes at 110 volts, with 25 per cent overload. Units or banks of glass-bulb rectifiers of 2 250-kW rating for power purposes, and 1 200 kW for traction, are now in operation. Water is not required for cooling purposes, and the vacuum is dependent on adequate sealing of the

bulbs. In practice, the life of the bulbs is satisfactory, ranging from 4 to 9 years as a maximum.

With this type of rectifier it is usual on 3-wire systems to arrange for the main equipment to take care of the balancing, without the use of auxiliary balancers. This is effected by having one or more bulbs across the outers and one between each outer and the middle wire.

Automatic or remote control of rectifier equipments used for power, lighting, or traction, is usual.

The use of the copper-oxide metal rectifier has considerably increased, and the applications are now very numerous. The changing-over by many supply undertakings of their low-voltage d.c. networks to alternating current has created many openings for this rectifier.

The uses of metal rectifiers include the supply of direct current for magnetic valves, for temperature control, for magnetic chucks, clutches, and pulleys, and, under certain conditions, for the replacement of batteries in the operation of telephone systems.

Larger types are being used for electro-plating, for railway point-operating mechanism, and for electrostatic precipitation. In the last-mentioned application the metal rectifier, which is oil-immersed, is replacing the older type of mechanical rectifier, which is noisy and requires considerable attention. The efficiency of the metal rectifier is much higher than that of the mechanical type formerly used for this purpose. This is of considerable importance owing to the fact that such plant is usually in almost continual operation.

The employment of rectifiers for traction purposes has in some instances caused interference with communication lines. This has been removed by using smoothing condensers as part of a resonant filter, thereby eliminating any undesirable harmonics which may appear in the rectifier output.

Where the absence of noise is an important feature, lifts operated from an a.c. supply and using a.c. motors for hoisting often employ d.c. brake and control panels fed through a metal or bulb rectifier.

Generators and Motors.

There have been no radical changes in design or construction of either generators or motors during the last year or two. The fabrication or building-up of steel plates and sections by welding has become general, and practically the whole machine can now be constructed in this way, including such parts as rotors and pedestal-bearing housings.

The designs and outlines of machines built up from fabricated steel parts are becoming more pleasing and symmetrical in appearance, and the method lends itself to very rapid construction.

The use of ball and roller bearings has now extended to larger machines.

Many manufacturers now design their small a.c. and d.c. motors to include the drilling for the holding-down bolts, the height of the shaft centre, etc., so that for equivalent outputs they are interchangeable. This is a considerable convenience to makers and users of machine tools, pump fans, etc. So far there has been no general standardization throughout the industry in the direction of uniformity of fixing-bolt centres, etc.

Alternating-Current Generators.

For small isolated installations it is now the more general practice to install a.c. generators instead of d.c. machines. This is done in order to obtain the advantages of squirrel-cage motors, and to conform to the standard system of supply of the country. It has the additional advantage that a stand-by supply can be taken from the national system. Many of the machines constructed have been for use in conjunction with internal-combustion engines, chiefly for abroad.

High-frequency alternators are now used for the supply to high-speed, built-in-type motors for wood-working machinery and similar tools where the motors are required to run at speeds above 3 000 r.p.m. A similar field is in conjunction with motor drives, blowers, scavengers, and superchargers for internal-combustion engines.

The development of the induction furnace has resulted in another application of this type of alternator.

Direct-Current Machines.

The demand for d.c. machines is declining on account of the fact that many supply undertakings are changing, or have changed, their supply to a.c. distribution. In the same way all extensions, almost without exception, are being carried out by means of alternating current.

Such d.c. machines as are required, particularly those of large size, are becoming more and more special in their application. Further, where speed variation is necessary, it is now possible to meet practically all the usual applications by a.c. variable-speed motors.

There has been some advance in details of design, in the direction of better commutation, by improvement of brush gear and methods of cooling, thus enabling speeds to be raised and ratings increased. The effect has been to decrease considerably the weight per horse-power for a given speed. This has been more marked in the machines of larger size.

A number of high-voltage d.c. generators have been built for radio communication and are in successful operation. The potential difference across each armature of this type of machine is 12 000–15 000 volts. Here the progress has been in matters of detail and in improvement of the insulation of the windings.

Small high-voltage d.c. machines have been produced for use in connection with electrical precipitation apparatus required for recovery or dust-collecting plant. Four such machines having shunt characteristics are run in series to give 60 000 volts. The base of each machine is insulated and the frame is made alive at a potential corresponding to the mean value of the two commutators fitted to each armature (which consists of two windings). Each machine is coupled to its neighbour through insulated couplings.

The following are a few interesting examples of large d.c. plant recently manufactured in this country:—

(1) A twin drive, the first in this country, for reversible rolling-mills. The two twin motors together give 1 176 effective h.p. at 60–150 r.p.m., and a maximum of 4 060 h.p. They are connected in series on the 3-wire system, with a high-resistance middle wire which gives the motors sufficient tendency to run at the same speed

without preventing them from running at different speeds.

(2) For use abroad, a rolling-mill equipment, to give an output of 5 000 h.p. at 80–180 r.p.m., and a maximum of 18 000 h.p., equivalent to a torque of 160 metre-tons.

(3) For abroad, two 7 000-h.p. motors, each driving reversing bloom mills. These are the largest single-armature machines yet built here, each being capable of developing 7 000 h.p. at 50 r.p.m. and having an instantaneous peak-load rating of 20 800 h.p. They are designed for constant torque up to 50 r.p.m., and constant horse-power from 50 to 120 r.p.m.

Another reversing mill has been put to work, in which the pinion housings have been eliminated by connecting a separate motor to each roll; they are so connected together that they will accelerate and reverse at the same time. The armatures are connected in series, thereby ensuring that the turning moment of each roll is kept at a definite value, any necessary adjustment being made by altering the relative field strengths. Provision is also made for preventing the speeds from varying widely when there is no metal in the mill.

Live rolls are now in some instances being driven by a separate motor on each of the roller spindles, the usual gearing being thus eliminated.

The majority of drives by d.c. motors for rolling-mills, winders, and other heavy duties, are arranged for Ward-Leonard control. One rolling-mill equipment, with a 2 000-h.p. motor, is being constructed on the Krämer system, in which the slip-rings of the induction motor driving the motor-generator set are connected to the slip-rings of a rotary convertor, the d.c. output from the latter being used to drive an auxiliary d.c. motor on the same shaft as the induction motor, thus raising the efficiency of the set. By over-exciting the rotary convertor, the power factor of the induction motor is improved.

Another example is a large Ward-Leonard winder, which is of interest on account of the fact that it is the largest one installed underground. It is of the double cylindro-conical type, and the drum shaft is driven by two direct-coupled 1 425-h.p. d.c. motors, one at each end of the drum, running at 39·8 r.p.m., the two motors being connected in series.

One of the largest rolling-mills of its kind in this country has been put to work. This is a piercing mill employing a 3 000-h.p. shunt-wound compensated motor running at 125–175 r.p.m. and capable of developing an emergency peak of 9 000 h.p.

Alternating-Current Motors.

Progress with regard to a.c. motors, particularly in the smaller sizes, has been in the direction of improved design, with the object of placing their manufacture on a mass-production basis and of further reducing their weight and cost. The result is that the average weight per horse-power has been materially reduced, and, generally speaking, a better motor is now available for general use.

The extension of the areas in which there is an a.c. supply has increased the use and application of a.c. motors, particularly those of the squirrel-cage type. The reliability of this machine, incorporating a practically indestructible rotor of the cast-in type, makes it almost immune from breakdown. It is the general practice to make the frames of fabricated steel-plates.

Where the conditions are dusty, dirty, or damp, it is now more economical to employ motors of the totally enclosed, self-cooled (fan) type in place of the older totally enclosed machines, and even, in some situations, in place of the pipe-ventilated type. In this design of motor there are two casings; one around which the internal air in contact with the machine windings is circulated, and which is not in contact with the outside air; and the second through which the outside air is circulated by means of a fan, the cool air passing directly over the back of the stator core. Such a machine is less expensive than a totally enclosed machine of the same rating owing to the greater output possible per unit weight. The saving becomes more evident the higher the speed of the motor.

The field of application of electric driving is an ever-increasing one, and new applications and the extension of old ones are continually taking place. Instances of these are numerous, and the following may be mentioned:—The use of motors, consisting of stators and rotors originally developed for high-speed woodworking machinery, which are built into, and really form an integral part of, the machine itself, has now been applied to various machine tools such as drills, lathes, etc. Where speed-changes are required, 2-, 3-, and 4-speed change-pole induction motors may be used, and in some cases gears may be dispensed with in consequence.

An electro-hydraulic device is now available for operating large doors, heavy valves, brakes, etc. It is replacing the usual solenoid, particularly where smooth operation is very desirable. It lends itself also to use where remote control is required. The appliance consists of a small motor driving an impeller immersed in oil, used in conjunction with an oil-filled cylinder and a piston, and all assembled as one unit. The piston, being connected to the load by means of suitable mechanism, is raised as soon as the impeller creates sufficient pressure to start the load. These machines are at present available for duties requiring pressures ranging from 75 to 500 lb. per sq. in. at strokes of 2 to 5 in.

The high-torque motor having a double squirrel-cage rotor winding has, perhaps, not found the range of applications which its characteristics promised. It is chiefly used for lift work and where low starting-currents are essential. It is undesirable to employ it with a geared drive unless special precautions are taken.

The necessity for variable-speed a.c. motors has led to an extended development in this direction, and the a.c. commutator motor, already well established, is now built for comparatively large speed-ranges, which in some cases are as high as 20:1. The capacities now range from relatively small machines up to sizes approaching 500 h.p.

In addition to drives for paper-making machinery and for printing, both of paper and of textiles, their use now extends to lifts, bore-hole pumps, fans, and boiler-house auxiliaries.

A recent, noteworthy application of a large synchronous motor for direct coupling to a rolling-mill (the first of its kind constructed in this country) was

completed in the short period of 7 weeks. This rapid construction was made possible by using welded steel construction almost throughout for the mechanical parts.

For this type of drive, the synchronous motor has many advantages over the induction motor, such as a higher power factor, the elimination of phase-advancing equipment, a large air-gap, a higher efficiency, and simpler rotor construction. The starting characteristics are perhaps not so good as for an induction motor on account of the peak, but in practice this is not really of great importance on large systems.

The machine is started up entirely automatically by means of an auto-transformer, and at 95 per cent of synchronous speed the machine is pulled into synchronism by means of a reactor at the same time as the field is applied, the reactor then being short-circuited.

Rated at 7 500 h.p., the motor runs at 94 r.p.m., is capable of dealing with momentary loads of 18 750 h.p., and has a starting torque of not less than 108 per cent of full load. Cooling is effected by two electrically-driven fans circulating the air through two water-cooled air coolers, the whole system being totally enclosed. The machine is suitably wound for a 6 300-volt, 3-phase supply.

Fractional H.P. Motors.

Although there has been no marked change or development in the small or fractional horse-power motor, there has been a large extension in its field of application, and such motors are now being manufactured in quantities in this country. Weights have been reduced. The field of domestic appliances has been largely responsible for the growth in the use of such machines as washers, refrigerators, vacuum cleaners, and fans. Small power tools and coffee grinders are further applications.

These small motors are manufactured for both direct and alternating current, the types in more general use for alternating current being the repulsion induction motor and the split-phase type. Where high starting torque and low starting current are required, the repulsion motor is usually employed. These machines have wound armatures with single stator windings, and commutators and short-circuiting brushes. A centrifugal mechanism is provided, which automatically short-circuits all the commutator bars when the motor reaches the neighbourhood of two-thirds of its rated speed.

Where simplicity is desired, the split-phase motor is employed. This has two windings on the rotor, one a low-resistance main winding, and the other a high-resistance starting winding. The starting winding is cut out by means of a centrifugal switch as soon as the motor attains two-thirds of full speed.

For certain uses silent operation is essential, and the single-phase split-phase motor, in conjunction with one or two condensers attached to, or incorporated in, the motor frame, is coming into more general use. These machines have a relatively high efficiency and power factor, and their maintenance costs are small. The starting torque is, however, somewhat low.

Universal motors, capable of running with either alternating or direct current, are available. They have a series characteristic which involves speed variation, depending on the load. In order to obtain satisfactory results, however, it is advisable to use, wherever possible, motors designed for one system of supply only.

For d.c. supplies, motors are usually of the compound-wound type; and interchangeability as regards the fixing-bolt centres of both d.c. and a.c. motors of similar horse-power rating is usual.

Torque Motor.

The torque motor, which has been in use for some time abroad for indicating the positions of lock-gates, sluices, etc., has now been applied in this country wherever motion of any kind has to be reproduced at a distant point, or wherever any mechanism has to move by an amount proportional to the difference between the motions of two other mechanisms.

The apparatus consists of a generator (or transmitter) and a motor (or receiver). The motor takes the form of a small 3-phase induction machine with a shuttle-wound rotor having definite poles and a winding which is connected through slip-rings to an external a.c. supply. The generator is of the same construction and is connected to the same supply. The transmitter and receiver are connected together by means of three pilot wires.

When the a.c. supply is switched on, the rotor of the receiver, being free to move, takes up the position of the transmitter and will follow any movement of the latter. When the position of the two rotors is in exact correspondence the voltage induced in the receiver stator is equal to and balances that in the transmitter stator, and no current flows in the stator. If the rotor of the receiver is prevented from taking up a position similar to that of the transmitter, the induced voltages in the two stators will no longer be equal and a current will flow which reacts on the rotors, setting up a torque. The transmitter is restrained mechanically, consequently the receiver rotor takes up a position corresponding to that of the transmitter.

Torque motors may also be used as engine-room indicators for the speed control of pumps, and the opening and closing of valves. Another use is to operate in step the brush gear on two (or more) variable-speed a.c. motors, in order to prevent either machine being overloaded when two driven machines are required to be mechanically coupled in order to run material through both in series, and when the location of the motors prevents a similar connection between their brush-operating gears.

Other similar uses are in connection with printing presses, and when several motors coupled to one machine, such as a sectional-drive paper machine, are required to run at different speeds, but where it is necessary to maintain a definite relation between the speeds of the motors.

Another interesting application is the control of the valve which regulates the amount of fluid in the hydraulic coupling of a motor-generator supplying an electric winder. This permits the speed of the generator and flywheel to drop when on peak load, enabling the flywheel to give up its energy while the motor continues to run at constant speed. Incidentally, this allows a synchronous motor to be used instead of an induction

motor, and consequently improves the power factor. The effect of this control on the power taken from the line is that the input of electrical energy is practically constant, whatever may be the load fluctuations imposed by the winder.

Frequency Changers.

There has been a localized demand for frequency changers in those districts where the frequency of the supply has been changed to the standard of 50 cycles per sec. In some cases these frequency changers have been so constructed that they can be conveniently transported either by rail or by road. They are made reversible and have been built up to capacities of 625 kVA at 600 r.p.m. It is necessary to arrange the 50-cycle stators so that they can be rotated, in order that the machines may, if desired, be run in parallel with other sources of supply and provide phase control.

It may be appropriate to mention here that a.c. motors of both the squirrel-cage and wound-rotor types have been developed suitable for use on non-standard frequencies, and which can be run on a frequency of 50 later when the supply is changed over. The windings of these motors are arranged on the split-pole principle. With this type of motor it is generally possible to obtain, at some slight sacrifice of efficiency and power factor, about 80 per cent of the rated output of a single-frequency machine.

Small frequency changers of the induction type have been developed for use in connection with high-speed motors, usually of the built-in type, such as those required for woodworking machinery. A further development of this frequency changer requires only one frame with two separate windings on the stator, each wound for a different number of poles, and with one winding on the rotor, which is fitted with three slip-rings. Relatively to one stator winding the rotor is short-circuited and runs as a squirrel-cage motor, but relatively to the other stator winding the rotor forms the secondary of a frequency convertor. The frequency obtained depends on the pole combinations for which the stator is wound; this ratio is usually either 3 to 1, or 6 to 1. This machine, when working with the 6:1 ratio and supplied at a frequency of 50, gives a 300-cycle per sec. output, enabling a speed of 18 000 r.p.m. to be obtained with a 2-pole motor.

Testing Machines.

The increase in the development of high-voltage cables, and the consequent general demand for high-voltage testing facilities, have produced alternators which, when used in conjunction with a harmonic analyser, are capable of giving practically a pure sine wave.

Control Gear.

During the last two or three years the increase in a.c. as compared with d.c. supply has resulted in development being more pronounced in connection with apparatus for controlling a.c. plant.

Thermal overload trips are now usually preferred to magnetic trips, being simpler and more compact. A change in the design of the thermal overcurrent element has been brought about by the demand for a higher instantaneous tripping value than could be obtained with the original designs, owing to the fact that these had a characteristic too rapid to give the required setting. The element may now take the form of a bimetal strip spirally wound and placed inside a porcelain tube which is heated by metal heaters placed on the outside of the tube, one strip being connected in each phase. As the temperature inside the tube tends to rise, the spiral unwinds and operates the tripping mechanism.

Small squirrel-cage motors, of sizes which may be connected direct to the line, are now generally switched on by air-break contactors, which serve both as the starting and as the overload-protection unit. This method of starting small squirrel-cage motors is a natural development, as the operating coil of the contactor serves as a no-volt feature, and the thermal overload relay, tripping by means of the operating coil of the contactor, provides a combination which is very little, if any, more expensive than a hand-operated device fitted with an overload and no-volt release. The combination, being suitable for remote control by push-button, is more convenient for operation than the hand-operated device with most industrial machine applications. It consequently results in a saving of time and is less liable to damage arising from mishandling by unskilled operators.

These last considerations are resulting in the more common use of automatic starting devices embodying star-delta connection, even for the larger sizes of motors, although the initial cost of the automatic combination is rather more than that of the hand-operated type. The use of automatic control in this country was at one time limited to applications such as the automatic starting of air compressors, hydraulic pumps, etc., where the motor had to be started and stopped according to some particular conditions in the apparatus controlled. The use of automatic devices for time-saving, and for making the operation independent of unskilled labour, except in so far as pushing a button is concerned, has been common practice in America for many years. The advantages of this method are now appreciated in this country, and many manufacturers have placed on the market reliable equipments of this kind, the cost of which is little in excess of the hand-operated devices.

Auxiliaries used in garages are an example of some of the most recent developments in automatic applications. The small air-compressor and pumping equipments, which are now being installed in most of the large garages for inflating tyres, and for lubricating and washing cars, are in practically all cases started automatically and controlled by special air-compressor or hydraulic-pressure governor switches.

Where plant has to be stopped quickly under emergency conditions, such as occur in rubber mills, one or more suitably disposed push-button controls are provided which, by operating contactors, reverse two of the phase leads to the 3-phase motor. At the same time a resistance is inserted in the rotor circuit in order to absorb the stored energy of the system; and immediately the motor starts to reverse, it is automatically disconnected from the line.

Another method of achieving the same result is to use

a magnetic clutch in conjunction with a solenoid-operated brake fed from a d.c. supply. The opening of the supply to this circuit by a control push-button disconnects the motor from the driven machine and applies the brake at once. The clutch may also be used to run the motor up to full speed before applying the load.

For a.c. circuits up to and including medium voltage (650 volts) the air-break device is most commonly used for starting and reversing equipments, the reason for this being that for devices which are operated frequently the wear on the contacts, due to the arcing, is generally less for air break than for oil. The difference in the wear is due to the fact that, in the air-break apparatus, blow-out and similar devices can be provided which cause the arc to move rapidly away from the contacts normally carrying the current, the arc being cooled as it is drawn over the arcing contacts past arcing horns and up the sides of the arc chutes; whereas in oil the arc is confined by the oil to a very small region and all the energy is concentrated on the metal of the contact at this spot, resulting in fusing.

The use of the oil circuit-breaker is still the best method of dealing with short-circuits (particularly in view of recent developments), owing to the fact that very large amounts of power can be ruptured in a small space; and, as the operation is infrequent, the wear on the contacts caused by arcing is not the most important factor.

It seems to be more generally realized now than formerly by those responsible for plant lay-outs that, where a number of small motors, operated by correspondingly small control devices, are connected to a circuit fed directly through a large transformer, the thermal type of relay is the best form to use on the small control devices, short-circuit protection being provided by a main oil switch controlling a group of such small motors. The thermal overload protection has an inherent time-lag which allows the oil switch having the coil trip to operate and clear the circuit before the small control unit, which lacks the necessary rupturing capacity, functions.

In some instances it is also good practice to operate the thermal devices from small current transformers having a special characteristic such that the secondary current which flows through the thermal relay will not be proportional to the primary current at high overload values, and will never exceed, say, three or four times full load, in order to ensure that the small thermal device will not be damaged under the worst short-circuit conditions. This however, is only necessary in exceptional cases.

Photo-Electric Cells.

The photo-electric cell is now coming into frequent use to control the operation of various machines (apart from sound-reproducing equipments), particularly where such operations call for very accurate timing, and where the material being manufactured, or the operating mechanism, is too delicate or too small to operate the conventional types of electrical or mechanical gear.

Applications such as the following may be cited:—To shut down a machine in the event of the breakage of a fabric; the counting of objects passing on a conveyor belt; the counting of traffic; and the control of operations by approaching vehicles.

Further applications include the feeding of special supplements, which require to be printed separately at low speeds, into high-speed printing presses, where very precise registering is essential in order to ensure correct folding and cutting.

Another use is in tube mills, where the time for handling the metal is very short owing to the rapidity with which the tubes follow one another. The operations are now successfully controlled by means of photo-electric cells, in conjunction with suitable amplifiers and contactor gear. Use is also being made of this type of cell to indicate the density of smoke emitted from a chimney stack.

Welding.

The technique of electric welding is already well known, and its increased use in the fabrication of all types of machines, tanks, drums, and many other applications such as the repair and building-up of worn apparatus, including railway crossings and frogs, has led to a growing demand for welding plant, both for direct and for alternating current. The most recent addition to the various systems already in use is that known as the atomic hydrogen welding process, which is a combination of the metallic arc and gas methods in which the arc is struck between two tungsten electrodes in an atmosphere of hydrogen. This results in the dissociation of the molecular hydrogen into atomic hydrogen, the process rendering latent a large amount of heat. Immediately after passing through the arc stream the atoms recombine and in doing so give up the heat which has previously been absorbed in the arc. The plant required is simple and consists of an automatic control panel, transformer and adjustable reactance, and an automatic hydrogen valve.

The striking of the arc is under the control of the welder from the torch, and the opening of the hydrogen-gas valve on the bottle container is also actuated by the striking of the arc, the pressure being controlled to suit the conditions imposed by the work in hand. This method can be applied to almost any thickness of material, as the atomic hydrogen flame is far hotter than either the oxyhydrogen or the oxyacetylene flame. It has the great advantage that welding takes place in a very active, reducing gas, namely, atomic hydrogen. The weld is therefore free from oxides and nitrides, and practically pure iron is deposited, with little or no carbide left in the weld.

It is, perhaps, in connection with the ancillary apparatus required for electric welding that improvements have recently taken place, such as the automatic head, arranged to feed the electrode automatically, the rate of feed being governed by the length of the arc. The arc is struck and maintained automatically at a constant length. Either bare or covered electrodes can be used. By using an automatic head, the saving in time over welding by hand is very considerable.

Where it is impossible to use automatic welding, it is now usual to employ a continuous-feed system, particularly where a large quantity of weld metal is required to be deposited. The apparatus consists of a device

which feeds the electrode down the centre of the welding cable, the electrode being fed through a nozzle. The feeding mechanism is started by the operator striking the arc, and is stopped when the arc is broken. There is a saving of some 25 per cent in the time taken by this method over ordinary hand-feed welding, and, in addition, waste due to scrap ends of electrodes is eliminated. It has the added advantage that heavy welding currents can be employed and the welding speed increased up to the capacity of the operator.

In the early stages of automatic and continuous feed welding it was only possible to use bare electrodes, but special covered electrodes having de-oxidizers embodied in the covering material are now available.

For repetition work, a fully automatic profile welder has been constructed in which the welding head is constrained to follow a prescribed path set by a template, the rate of feed of the electrode being governed by the voltage across the arc.

Developments in resistance welding, used (amongst other purposes) for making small tubes, are mainly in modifications to the construction of machines to meet particular requirements.

The application of electric welding for structural work such as buildings, bridges, etc., has made little progress in this country compared with abroad. This is attributable, no doubt, to the restrictions imposed by existing building regulations. It is hoped that these will be modified before long, so that increased use may be made of this method of construction and benefit obtained from the reduction in cost which would follow.

Electric welding has now reached a stage when welds can be made with such reliability that its use in many industries has become essential. One of the latest uses is the construction (abroad) of a large transformer rail-transport vehicle, the entire body of which is of welded construction. The tare weight is some 60 tons, and the capacity just under 120 tons.

It is no doubt felt desirable by users of welded assemblies such as girders, drums, and similar structures, that some ready means of testing the finished weld should be available which does not involve proving it to destruction, but which is at the same time reliable and yields a quick result. Such a method has been developed recently in the form of a readily transportable X-ray testing equipment, which can be employed on welded materials up to 4 in. in thickness. It consists of a high-voltage generator in an earthed, metallic housing, and an X-ray tube suitably shielded so that there is no danger to the operator from X-ray radiation. The time required for exposure has now been considerably reduced by increasing the energy input to the X-ray tube, by special methods of focusing, and by the development of special fast intensifying screens for short wavelengths.

Power Factor Improvement.

The fact that an increasing number of supply undertakings offer more favourable tariffs for high power factor, and in some cases impose penalties when the value falls below a certain percentage, has stimulated the development of a.c. motors capable of improving the power factor of the load, although very little that is new has been produced except in matters of detail. It has had a similar effect on the use of static condensers for the same purpose. Where large motors form part of the equipment of a factory or building, a favourable opportunity is afforded to install a type which will enable the power factor of the installation to be improved.

Several types of machine, such as the synchronous motor, the synchronous induction motor, the induction motor in conjunction with a phase advancer, and the commutator motor, are already available for this purpose. The shunt-type phase advancer used in conjunction with an induction motor is, however, coming into more general use, and in several applications is being preferred to the synchronous motor. In addition, several variations of the induction motor fitted with a commutator are now available for power factor correction. This type of machine provides an economical method of obtaining improvement where the installation is a small one.

There has been little call for synchronous condensers in this country, and those that have been constructed have mainly been for use abroad. The present tendency is to operate these at higher speeds than formerly, and machines of 20 000 kVA running at 1 000 r.p.m. have been manufactured in this country. If, on the other hand, the equipment consists of a number of small motors, or the large motors are only run intermittently, it is more usual to install static condensers.

Until recently it has been customary, and more economical, to employ an auto-transformer with static condensers for standard low voltages. As a result, however, of developments in design, static condensers up to 250 kVA can be produced for connection directly to the low-voltage supply, thus dispensing with the auto-transformer, with the added advantage of some gain in efficiency.

It is now possible to obtain condensers for the purpose of power-factor correction, suitable for direct operation on circuits up to and including 6 600 volts. The static condenser has the added advantage, which is also shared by the phase advancer, that any defect does not incapacitate the power unit.

The increased use of luminous tubes, mainly in the form of advertising signs, has brought with it difficulties, because these tubes operate at low power factors when working on a.c. circuits. Supply undertakings are now insisting on some measure of correction, which is usually effected by incorporating a static condenser in the sign equipment.

Electric Furnaces.

Much more general use is now being made of electric furnaces, both for the smelting of steel and brass and for heat treatment of special steels and alloys. The ease of control makes their use very desirable in view of the delicacy of some of the processes. The smelting furnaces are now made in capacities ranging from 100 to 2 000 lb. per charge.

One of the recent developments in electric furnaces is the coreless induction type, which, in design, is somewhat similar to an air-cooled transformer the primary of which is a single helix of water-cooled copper tubing, and the secondary of which is the conducting mass of the metal

to be smelted, located within the primary. Induced currents circulate in the outer part of the charge and thereby heat it. There are no electrodes, and there is little wear on the crucibles. No part of the furnace is at any time hotter than the charge. A modification of this furnace is one embodying a special alloy steel core to concentrate the magnetic field inside the crucible, thereby allowing the use of steel for encasing the furnace and also decreasing the current consumption.

For heat-treatment furnaces, involving temperatures up to 1 000° C., the 80/20 nickel-chrome resistor holds the field. In certain cases special metallic resistors are being operated at temperatures up to 1 250° C. The application of the high-frequency furnace to the production of this alloy has ensured better mixing of the nickel and chromium, prevention of carbon contamination other than that contained in the raw material, and a reduction in oxides and other impurities. The result of these improvements has been to increase the life of the element and, hence, the reliability of furnaces.

For high-temperature furnaces, resistors are being used which enable heat-treatment operations up to 1 350° C. to be performed. Since, however, carbon is used in these resistors, they have the common disadvantage of increasing in resistance after a comparatively short period of use. Where it is necessary to maintain the original rating of the furnace, ballast resistors, or a transformer with tappings for varying the voltage, must be used.

A feature of the electric furnace is the ease with which the internal atmosphere can be controlled; thus the formation of scale is prevented, in a new type of furnace, by burning a small quantity of air and coal gas in a combustion chamber outside the furnace chamber and forcing the products of combustion into the heating area.

For low-temperature heat treatment and tempering, a recently developed furnace makes use of a centrifugal fan which is embodied in the base of the furnace and causes air, heated by the surrounding elements, to circulate rapidly around the charge, thus ensuring uniform and rapid heating.

Experience in the disposition of heating elements in a rectangular furnace has enabled manufacturers to design chambers in which the difference in temperature between any two points in the furnace will be less than 5 degrees C. This uniformity in temperature has made possible the "Nitrard" process, by which steels are case-hardened in a nitrogenous atmosphere.

The facility with which elements can be graded and disposed is also leading to the development of conveyor-type furnaces, by which the rate of heating-up, soaking, and cooling-down can be accurately controlled.

Accumulators.

Lead-Acid.

Such development in design as has taken place is mainly in details in evolving types for particular applications, such as the thick pasted-plate type of lead storage-battery for use as tripping batteries for switch-gear. These are generally used in conjunction with small trickle chargers, which maintain the batteries in a healthy condition for long periods. They are gradually replacing primary batteries for such applications as railway signalling, telephones, and stand-by duty.

Some measure of standardization has been accomplished in connection with the sizes of plates, the required capacities being obtained by utilizing the requisite number of standard plates.

Alkaline.

Improvements have been effected in this type of cell, notably in the direction of a marked reduction in the internal resistance of the cells, thus rendering them suitable for telephone work and for the starting of internal-combustion engines of both the petrol and Diesel types, including those on heavy commercial road-vehicles.

ELECTRIC TRACTION.*

By F. Lydall, Member.

During the last three years conditions throughout the world have not been favourable for any considerable development of electric traction. A good deal of what has been done consists of the completion of schemes already in hand or definitely decided on before the end of the year 1930. There has, nevertheless, been some progress in various directions; a few advances have been made in technical matters; important investigations have been carried out; and certain existing electrifications have been extended.

(1) General.

Practically no change has occurred in respect of the electrical systems on which electrification schemes have been carried out. In most countries the system has been standardized, by general consent if not by regulations: either the direct-current system as in Great Britain, France, Spain, and Holland, or the single-phase alternating-current system as in Central Europe, Norway, and Sweden. In Italy, both the 3-phase alternating-current and the 3 000-volt direct-current systems are employed, the latter mainly south of Florence. In the United States there has been no obvious move towards standardization of system, each individual electrification scheme being considered independently.

In the electrical equipment of locomotives there has been development along two lines, both with the object of facilitating the use of alternating current at industrial frequency. The necessary financial arrangements have been made to introduce on the Hungarian Railways the system devised by the late Dr. Kando. This system employs on the locomotive a phase convertor supplied with single-phase alternating current at 50 frequency from a 16 000-volt overhead line, which delivers to the driving motor or motors 3-, 4-, or 6-phase current at the same frequency. The motors are designed for this frequency, and are arranged by means of special windings and pole-changing connections to give several economical running speeds. On the Hungarian Railways each locomotive has a single 2 500-h.p. motor with two primary windings and 16 slip-rings on the rotor, and a single secondary winding in 48 groups on the stator. The primary windings, fed from the phase convertor at about 1 000 volts, can be connected up to give 72, 36, 24, or 18 poles, which correspond to synchronous speeds of 83, 166, 250, and 333 r.p.m. The secondary winding is tapped at 48 points, and connections from the taps are taken to a liquid rheostat.

For the other development, intended to enable single-phase alternating current at industrial frequency to be used, the mercury-arc rectifier is employed. As in a wireless valve, the passage of current from the anode to the cathode can be controlled by a grid, the potential of which is varied as desired from an outside source. Thus, if an alternating voltage be applied between the anode and the cathode the resultant unidirectional fluctuating anode current can be completely stopped by charging the grid negatively. If the charge is reversed the anode current is restored. By suitably timing the periodic reversal of the grid charge, the striking of the arc which forms the anode current can be delayed to any point in the half wave of the alternating voltage, after which the current continues to flow until the end of the half period. Thus the anode current can be composed of complete and partial half-waves, which, when smoothed out by choking coils, constitute half waves of current of any desired frequency. By duplicating the arrangement so as to give two such half waves in succession, one positive and one negative, an alternating current of a new and, if desired, variable frequency is obtained.

For traction purposes this arrangement has been adapted for use with what is in effect a single-phase variable-frequency commutatorless series motor. The stator has two polyphase windings, and the rotor a single field winding to which connection is made by a pair of slip-rings. The frequency convertor is a mercury-arc rectifier with two sets of anodes, each anode being provided with its own grid. The stator windings of the motor are star-connected, and the two centre points are connected to the two ends of the secondary winding of the main single-phase step-down transformer, the primary of which is fed from the overhead line. The free ends of the stator windings are connected to the two sets of anodes, and the cathode is connected through the rotor field-winding to the midpoint of the transformer secondary. The stator and rotor windings are therefore in series and the motor has a series characteristic. The two sets of grids are charged from a small motor-generator through a multiple contact-maker coupled to and revolving with the main motor. Thus the frequency of the supply to the motor is determined by the speed of the motor itself, and no commutator is required. The running of the motor is dependent on the voltage applied to its windings, and this is controlled quite simply by varying the settings of the two contact-makers.

For this system it is claimed not only that single-phase alternating current at industrial frequency can be used, but also that the equipment of the locomotive is considerably simplified by the elimination of transformer tappings, step switches or contactors, and reversers, while regenerative braking is obtainable without any complications. One of the original 3-phase locomotives for the Simplon Tunnel is being equipped on this system for trial purposes with a frequency convertor and a pair of 500-h.p. motors.

* A review of progress.

In the mechanical design of electric locomotives no outstanding novelty has been introduced during the last three years. With few exceptions new locomotives have been built with individually-driven axles, usually with some degree of flexibility in the gearing. The use of side rods continues in Sweden, the north of Italy, Austria, and Hungary, but on the score of cheaper maintenance opinion generally is in favour of individual drive, and future developments are likely to be in this direction, even in those countries, such as Germany and Switzerland, where side-rod designs have been extensively used in the past.

There is, in general, and especially in the United States, a tendency to provide for higher speeds, not only on main lines but also in suburban and interurban services. Thus the new 3 750-h.p. electric passenger-locomotives which are being built for the Pennsylvania Railroad are intended to haul trains of 1 000 tons at a steady speed of 90 miles per hour on the level; whilst the motor-coaches of the Delaware, Lackawanna, and Western Railroad, each of which is equipped with four 235-h.p. 1 500/3 000-volt motors, are designed for a balancing speed of 65 miles per hour, the trains being composed of equal numbers of motor-coaches and trailers. The most recent equipment of interurban railways in the United States includes light-weight cars each provided with four 100-h.p. motors designed for maximum speeds in service of 75 to 82 miles per hour.

The only other technical development of note during the last three years in connection with rolling-stock is the production of a new traction battery, the invention of Prof. Drumm of University College, Dublin. This is an alkaline cell, in which, as in other alkaline batteries, nickel oxides are used for the positive plates. The special feature of this cell is that the negative plates consist of nickel gauze grids, and the electrolyte is a solution of zinc oxide in potash. On being charged the nickel grids become coated with metallic zinc. The voltage of this combination is substantially higher than that of the ordinary alkaline cell, viz. about 1·86 volts when fully charged, as compared with about 1·34 volts. This in itself is an important advantage, but the chief feature which is claimed for it is that very heavy currents can be passed through the cell during both charge and discharge.

The battery as at present made consists of 264 cells with a capacity after a full charge (taking about 4 hours) of 600 ampere-hours. In practice the capacity is related to the time of charge, and the normal routine, as adopted on the Great Southern Railways of Ireland, on which an experimental train has been running for some time between Dublin and Bray, is to charge and discharge the battery 20 times a day, the duration of each charge, which takes place at the end of each journey, being 20 minutes. Under these circumstances the input on each occasion is about 150 ampere-hours; the average voltage per cell on charge is 2·03 and on discharge 1·65, and the average overall efficiency under service conditions about 75 per cent. The weight of each cell is 112 lb. Thus the output per cell corresponding to a 20-minute charge is 2 watt-hours per lb. During discharge the current can, when required for accelerating the train, be raised to 1 000 amperes without injury to the battery. Reliable information as to the capital and maintenance costs is not yet available, but the makers claim that a life of several years in regular service should be obtained.

For traction substations the mercury-arc rectifier is now recognized as having advantages which cannot be obtained from the rotary convertor or the motor-generator, while the disability from which it previously suffered, viz. liability to flash-over or backfire internally, has been eliminated or so far reduced as to become unimportant. Such occasional flash-overs as do occur do not damage the rectifier. Two methods are in use for dealing with them: (1) the high-speed direct-current circuit breaker between the rectifier and the d.c. busbars is fitted with a reverse-current trip to prevent any feeding-back into the fault from the busbars, while the a.c. circuit breaker cuts off the supply from the high-tension side; (2) a quick-acting overload relay is provided in connection with the supply to the grids, which cuts off the periodic positive charge immediately a backfire occurs, and thus prevents the arc striking again. Of these two methods the latter has the advantage that there is no need for either of the circuit breakers to open in order to clear the fault, and this is especially to be welcomed in regard to the a.c. circuit breaker, which otherwise has to open on a dead short-circuit and may itself require attention after one or two such occurrences. Mercury-arc rectifiers are now manufactured by a number of firms on the Continent, in this country, and in the United States. They are being extensively used on many railways already in operation, and are being installed in large numbers on other railways where electrification is in progress.

In regard to the supply of power for railway working, the desirability of combining the railway load with the general and industrial load and relying upon public supply undertakings is clearly recognized, as shown by the two lines of development mentioned above. Arising from this and from the progress with the national "grid" in this country and the consequent widespread availability of cheap power, the Government, in September 1929, appointed a small Committee known as the Weir Committee, consisting of Lord Weir, Sir Ralph Wedgwood, and Sir William McLintock, to investigate the economic and other aspects of the electrification of the railway systems in Great Britain, with particular reference to main-line working. The publication of their report in March, 1931, was in some ways the most important event in the sphere of electric traction in the last three years, as it dealt with the subject in a way which had previously been hardly possible. Evidence was taken from a number of witnesses on the technical, commercial, and financial questions involved, and the Committee's conclusions were based on this evidence and on the results of two detailed investigations into hypothetical schemes, one on the London and North Eastern Railway and the other on the London, Midland, and Scottish Railway. These investigations were undertaken because the Committee considered, after reviewing all the information available, that "the reasons which have led to the great majority of main-line electrifications abroad are such that they do not apply to the same extent to British conditions, where coal supplies are ample,

hydro-electric resources scanty, and, generally speaking, there are few severe gradients or long tunnels."

Both investigations were carried out by the Committee's consulting engineers with the assistance of the officers of the two railways. The scheme provisionally selected for the London and North Eastern Railway included the main line from King's Cross to Doncaster and Leeds, and the following sections: Nottingham to Grantham, Lincoln, and Boston; Doncaster to March; and Peterborough to Grimsby, with certain connecting lines. The conclusions reached were: (1) The net capital expenditure by the railway would be £8 646 323, on the assumption that the Central Electricity Board would provide the substations and all connections between them and the grid; (2) the annual saving in working expenses would be £624 630, i.e. 7·22 per cent of the net capital expenditure, on the basis that the railway would purchase power from the Central Board as direct current at 1 500 volts at a price of 0·5d. per unit.

The provisional scheme on the London, Midland, and Scottish Railway included the section of the main line between Crewe and Carlisle and the branch line from Weaver Junction to Liverpool. In this case the conclusion was not so favourable to electrification; the net capital outlay was estimated at £5 123 370 and the saving in working-expenses £127 766, or a return of $2\frac{1}{2}$ per cent on the net capital. The difference in the return on the net capital in the two schemes is attributed to two factors. In the one case, the London and North Eastern Railway, it was assumed that all traffic would be worked electrically irrespective of whether the trains travelled beyond the limits of the sections considered, and all shunting in the goods yards and elsewhere would be worked by electric locomotives; in the other case it was assumed that shunting work would continue as at present with steam, and that on the sections considered only those trains would be worked electrically which were confined to those sections, or which could be so worked without seriously interfering with arrangements on adjacent sections.

On the results of these investigations and other inquiries the Committee formulated the following conclusions: (*a*) That except where some special conditions obtain, the carrying out or even the investigation of limited schemes is unlikely to prove worth while; (*b*) that there is only one way by which the full benefit of railway electrification can be obtained in Great Britain, and that is by the complete substitution of steam haulage by electricity. Arising out of these conclusions, and with the assistance of the estimates of capital cost and working-expenses in the two detailed investigations, a general estimate was prepared for the electrification of the whole railway system of the country. This showed that the net capital cost to the railways would be about £260 000 000, with an addition of approximately £80 000 000 to be incurred by the Central Electricity Board and other authorized undertakers on generating-plant, transmission lines, and substations; and that the financial result in net annual savings of working-expenses and additional revenue on haulage of coal to power stations would be £17 550 703, equal to 6·7 per cent of the net capital outlay of the railways.

The report referred also to the general incidental advantages of electrification and discussed the possible risks and contingencies and its effect on the railway staff, the national coal-output, and industry, but did not submit any definite recommendations. The report was considered by the Government and by the railways, and certain discussions took place, as the result of which the railways made it clear that, while they took a favourable view of electrification, to a greater or less extent depending on further examination of specific proposals, they could not in the prevailing circumstances contemplate embarking on any electrification programme without some measure of financial assistance, by way of contribution or guarantee, from the Government. While the position was being considered the financial crisis of August, 1931, developed, and since then no further moves have been made.

So far as tramways are concerned the general trend continues in the direction of the use of light-weight motors, of which a large number have been supplied during the last two years. Further developments have been made in the design of trucks on which the motors are mounted with a flexible connection to the driving axles, with a view to reducing the unsprung weight and therefore the impact on the rails.

(2) Statistical.

The review of progress published in the January, 1930, issue of the *Journal* (vol. 68, p. 167) contained particulars of electrification schemes in hand in most of the principal countries of the world, and in this review it is therefore unnecessary to do more than record the completion or progress of these schemes and mention any fresh schemes that have since then been initiated.

Great Britain.

The electrification on the Southern Railway is still the most extensive and most important in this country. During the last two years extensions have been opened for traffic on the Hounslow–Windsor line (13 route miles, $26\frac{1}{2}$ track miles), the Dartford–Gravesend line (7 route miles, $14\frac{1}{4}$ track miles), and the Wimbledon–West Croydon section (6 route miles, $8\frac{1}{4}$ track miles).

An advance from suburban to main-line electrification has been carried out on the same railway. The suburban system has been extended from Coulsdon North to Reigate, Brighton, and West Worthing, this extension comprising 52 route miles, or $162\frac{1}{2}$ single-track miles. The first portion, between Coulsdon and Three Bridges, 15 route miles, was opened for traffic on the 17th July, 1932; the remainder, from Three Bridges to Brighton and West Worthing, on the 1st January, 1933.

The electrical system for this main-line extension has not been changed from that already adopted for the suburban lines, viz. direct current at 660 volts, with third rail and track return. The electric operation is confined to passenger trains, which consist entirely of multiple-unit stock; no electric locomotives are to be used, at all events for the present.

The trains for the suburban extension are made up of motor-coaches and trailers, each motor-coach being equipped with two 275-h.p. motors; each train unit comprises two motor-coaches and one or two trailers.

For the service between London and Brighton the traffic is operated by high-speed multiple-unit trains of six coaches, some being Pullman and restaurant cars. Two such units to form a 12-coach train are used during the busy hours. The schedule time for a non-stop run to Brighton from Victoria, a distance of 52 miles, is 60 minutes. Each single train contains two motor-coaches, each equipped with four 225-h.p. motors, the total weight of a 6-coach train being 261 tons. The balancing speed on the level is 63 miles per hour, but during the run the speed occasionally rises to 73 miles per hour. Equipments for 26 trains have been provided.

Power for the operation of traffic south of Purley is drawn from the grid. For distribution to the substations a single 33 000-volt line has been provided, connected to the grid at the two ends, viz. Croydon and Brighton, and at one intermediate point at Three Bridges. Thus each substation has two alternative sources of supply. Three-phase power at 33 000 volts, 50 frequency, is converted to direct current at 660 volts in 18 substations, spaced at approximately equal intervals along the 52 miles of route south of Coulsdon. Each substation contains a single 2 500-kW mercury-arc rectifier, capable of giving an output of 4 000 kW for 5 minutes.

The electrification of the Manchester, South Junction, and Altrincham Railway has been completed. This is the first passenger line in this country to adopt the 1 500-volt direct-current overhead system, the Shildon–Newport line being used only for mineral traffic. Compared with other suburban schemes this development is quite small, the total mileage of track equipped being only 28, corresponding to a route mileage of $8\frac{3}{4}$. It may, however, be the first step in the electrification of a number of suburban lines radiating from Manchester. The design of the track equipment follows usual modern lines, with a sectional copper area for each track of 0·85 sq. in. The rolling stock consists of 24 motor-coaches and 44 trailers. Each motor-coach is equipped with four 330-h.p. motors, is 61 ft. 8 in. long over buffers, weighs unloaded 57 tons, and seats 72 passengers. The 3-coach unit weighs unloaded 118 tons, and has accommodation for 40 first-class and 226 third-class passengers. Power in bulk is taken from the Longford Bridge substation of the Stretford and District Electricity Board at 11 000 volts, 3-phase, 50 frequency, and is converted to direct current at 1 500 volts in two substations, each of which contains converting plant of 4 500 kW capacity. At one substation, that at Old Trafford, the plant consists of one mercury-arc rectifier and two pairs of rotary convertors; in the other substation, at Timperley, there are three pairs of rotary convertors. The latter substation is unattended and is controlled from Old Trafford by Midworth distant-repeater gear.

The opportunity has been taken to introduce considerable improvements in the service. Under steam operation the time for the journey of a stopping train from London Road, Manchester, to Altrincham was 27 minutes. Two new stations have been constructed at which the stopping trains call, but in spite of this the time for a single journey has been cut down to 21 minutes. There are also a number of express trains which complete the journey in 13 minutes with two intermediate stops. During the rush hours the trains run at 4- and 5-minute intervals, and during the slacker periods every 15 minutes.

On the Barking–Upminster section of the London, Midland, and Scottish Railway, two additional tracks have been constructed and electrically equipped with a 600-volt third rail and a fourth rail. This constitutes in effect an extension of the existing Bow–Barking line on which District trains were already running as far as Barking. The new route mileage is approximately $7\frac{3}{4}$ miles. On the London Underground system the Piccadilly Railway is being extended on the north from Finsbury Park to Cockfosters, a distance of $7\frac{1}{2}$ miles with 8 stations. For the first 4 miles the new railway is built in twin tunnels of 12 ft. diameter, after which the lines come to the surface, each tunnel being completed by a 50-ft. length of special tube 16 ft. in diameter to minimize the effect caused by the current of air due to the sudden change from the tunnel to the open, and vice versa. The construction is practically complete, and the first section, from Finsbury Park to Arnos Grove, a length of 4·46 miles, was opened for traffic last September.

France.

The Paris Metropolitan Co. is engaged in extending its underground system beyond the city boundaries into the nearer suburbs. Fifteen such extensions have been approved, and in some cases constructional work has already begun. Preparations are also being made for extension into the outer suburbs by the electrification of existing surface lines to be taken over from the present owners, the big railway companies. The first of the lines in the outer suburbs to be electrified is a 12-mile section of the Paris–Orléans Railway between Paris and Massy–Palaiseau, with a branch to Sceaux. This line, when electrified, will connect with the Paris Underground by an extension to the Place Saint Michel. It is expected that the new service will begin in January, 1933.

On the Paris–Orléans Railway no extensions of electrification have been completed since the beginning of 1930, but work is in hand on the sections Orléans–Tours, which should be ready for service in 1933, and Vierzon–Brive, which should be ready in 1935. These two extensions comprise 418 km of route, 908 km of running track, and 1 079 km of track, including sidings. The Midi Railway has also extended its electrical operation, and has added since the end of 1929 about 600 km of track and 92 electric locomotives. Still further equipment, to be completed in 1935, is in hand, comprising an additional 642 km of track. When this is in operation the total length of single track arranged for electric working will be 3 060 km.

Spain.

The studies of the Commission nominated by Royal Order in January, 1928, to consider the whole question of railway electrification showed that some 5 700 km should be converted immediately or should be more closely investigated. Accordingly it was announced

that the Government had authorized an extensive programme of electrification, beginning with 1 500 km, and a special Commission was nominated to supervise the work. Although the Commission is still in being, the change in the political situation has interfered with the carrying out of the programme. Nevertheless, the Compania del Norte has electrified the Irun–Alsasua section of its main line from the French frontier to Madrid, the lines from Barcelona to Manresa and to San Juan de las Abadesas, and the section between Ujo and Busdongo, a total of 616 km of single track.

On the State Railway operated by the Compania del Norte the line from Ripoll to Puigcerdá connecting with the Norte Railway to Barcelona and with the Midi Railway of France to Toulouse has been electrified, the length being 49 km. The Vascongados narrow-gauge railway between San Sebastian and Bilbao, with several branches, is equipped for electrical operation. In all cases the direct-current system at 1 500 volts is employed.

The Norte Railway electrification is now being extended to include the Bilbao–Portugalete line. For this extension the Metropolitan Vickers Co. are supplying thirty-eight 230-h.p. motors for the multiple-unit trains, the control apparatus being mostly built in Spain. The same company have recently supplied to the Norte Railway for service on the Irun–Alsasua section a 150-ton high-speed passenger locomotive of 3 600-h.p. capacity. This locomotive is of the type $2 - C_0 + C_0 - 2$, and measures 82 ft. overall. The body consists of a main cab pivoted on the two trucks, and the two sloping ends fixed to the trucks. Each of the six driving axles has a pair of 300-h.p. motors with Winterthur flexible drive, as first used on the passenger locomotives of the G.I.P. Railway. The 12 motors are divided into four groups of three motors wound for 500 volts. The wheel diameter is 1 560 mm, and the gear ratio 4·484 to 1.

Switzerland.

During 1930 the 3-phase system disappeared from those sections of the Swiss Federal Railways on which it had survived, viz. on the line from Brigue to Iselle through the Simplon Tunnel and on the Seethal Railway, and was replaced by the standard system, single-phase alternating current at 15 000 volts, $16\frac{2}{3}$ frequency. By the end of 1930 the Federal Railways had electrified lines totalling 1 075 miles of route and 2 352 miles of single track; the electric rolling-stock consisted of 307 passenger locomotives, 86 freight locomotives, and 56 motor-coaches.

As part of the second electrification scheme, which was mentioned in the last review of progress but which has since been expanded to include a total of 313 route miles, the conversion of the line, $23\frac{1}{2}$ miles in length, between Neuchatel and the Col des Roches was completed in October, 1931. It is intended to carry out the whole of this second scheme by 1936.

Mention should be made of two new and very powerful locomotives which have recently been delivered for operation of the St. Gothard line. These locomotives are of the type designated $1B_0\,1B_0 1 + 1B_0 1\,B_0 1$, and have been built by the Swiss Locomotive Co. with motors by Brown-Boveri in one case and by the Oerlikon Co. in the other. Each has a total weight of about 244 tons, with 20 tons on each of the 8 driving axles; and the overall length is 111 ft. $6\frac{1}{2}$ in. The specified operating conditions are that the locomotive must be capable of hauling a train of 600 tons at $38\frac{1}{2}$ miles per hour, or a train of 750 tons at 31 miles per hour, in either case up the St. Gothard gradients of 1 in 37; further, that by means of regenerative braking the trains must be held at a speed of 21·7 miles per hour down the 1 in 37 gradient. To meet these conditions the locomotive equipped by the Oerlikon Co. contains 16 motors, each with a capacity, according to the specification, of 450 h.p. on the 1-hour rating and 410 h.p. continuously. Actually the motors will give 550 and 520 h.p. respectively at the motor shaft. The 1-hour capacity of this locomotive is thus 8 800 h.p., corresponding to a tractive effort of 80 000 lb. (assuming a gear efficiency of 93 per cent) at $38\frac{1}{2}$ miles per hour. The two motors of each pair are connected in series, and the 8 pairs in parallel. Each pair is connected through a Winterthur drive with its own axle. In the other locomotive 8 motors of 925 h.p. are provided, each connected with its own axle through a Buchli drive. The maximum speed permissible is 100 km per hour. An interesting point in the mechanical design is that by means of a compressed-air cylinder above the middle axle of each half-locomotive, part of the weight on this axle can be transferred to the driving axles, thus increasing by 12 tons the total weight available for adhesion when the conditions of starting are difficult.

Italy.

Further extensions of electrification have been made on the Italian State Railways. The short section between Iselle and Domodossola was converted in 1930, but is worked by the Swiss Federal Railways under the Simplon Convention, the Swiss system being used, viz. single-phase alternating current at 15 000 volts and $16\frac{2}{3}$ frequency. Work is in progress and is nearly completed on the Cuneo–Ventimiglia–Savona section joining up at Savona with the existing network of electrified lines in Liguria and Piedmont, which includes the through line from Modane to Leghorn. The present extension is 130 miles in length, and the 3-phase system is being continued with 3 700 volts at $16\frac{2}{3}$ frequency on the contact lines.

The sections Spezia–Fornovo and S. Stephano–Sarzana, on the main line between Milan and Rome, were changed over to electric working last April, the two sections aggregating 96 km. The route passes through a mountainous district and the electrification has resulted in a saving of 45 to 60 minutes in the timing of the two night expresses. The electrical system is the same as on the Modane–Leghorn line. The completion of this electrification brought the total length of electrified lines on the State Railways to 2 034 km.

Another extension in hand is from Avezzano to Sulmona, a distance of about 65 km. This will complete the electrification of the line from Rome to Sulmona which was begun in 1928. This line is of interest on account of the use of 3-phase alternating current at industrial frequency (45 cycles per sec.) with 10 000 volts on the contact-lines.

In the South of Italy the 3 000-volt direct-current system has been adopted, and was applied in 1927 to the Foggia–Benevento section. This electrification has been extended to Naples, a distance of 96 km, and electrical working of through trains between Naples and Foggia started in November, 1931. Progress has also been made with the equipment of the direct line, 96 km long, between Bologna and Florence, using the same system.

It is reported that the Government has decided on the electrification of a further 5 000 km of main lines. This programme will include the completion of the network in Piedmont, the Florence–Rome, Rome–Naples and Naples–Salerno main lines, with other less important lines in the Venetian provinces. The main lines south of Florence are to be electrified on the 3 000-volt direct-current system.

Germany.

In South Germany, the electrification centred on Munich has been extended and the conversion of additional sections is in hand. A start has been made on the equipment of the tracks between Augsburg and Stuttgart. It is expected that this extension will be completed by the end of 1933, when the whole of the line from Stuttgart to the Austrian frontier at Salzburg, 195 miles in length, will be electrically operated.

It has also been decided to electrify the Wannseebahn, a suburban line $11\frac{1}{2}$ miles in length south-west of Berlin. This line will be linked up with the Ringbahn through a new interchange station. Electric working is to start in the summer of 1933.

Hungary.

Reference has already been made in the "General" section to the electrification on the Hungarian State Railways, on the system devised by Dr. Kando. The scheme comprises the equipment of the line from Budapest to Hegyeshalom on the Austrian border, a distance of about 122 miles, with a single-phase alternating-current overhead contact-line working at 15 000 volts, supplied from four step-down substations, and 36 electric locomotives, particulars of which have been given above. As the system adopted involves the use of alternating current at the commercial frequency of 50 periods per sec., no special railway power station or frequency-changing substation is necessary. Power is supplied from the Bánhida generating station of the Hungarian Transdanubian Electric Co., which contains three 21 000-kW 50-frequency turbo-alternators. The carrying out of this scheme has been made possible by an arrangement under which Great Britain granted to Hungary a credit of something over £3 000 000 under certain conditions as to the placing in this country of orders in connection with the electrification. The work is already well advanced, and electrical operation started last September on the first portion between Budapest and Komárom, about half-way to Hegyeshalom. It is hoped to complete the whole scheme in 1935.

Sweden.

Early in 1931 the Swedish Government decided to continue the electrification of the State Railways by equipping the line from Stockholm to Malmö, and also three connecting lines between this and the main line from Stockholm to Gothenburg already electrified. This scheme involves altogether the conversion of 535 miles of route, of which the Stockholm–Malmö main line accounts for about 360 miles, the total mileage of single track being just under 600. The complete scheme is to be ready for operation in the spring of 1934. Electric working has already started on two of the connecting lines, and the section of the main line from Stockholm to Norrköping, 100 miles in length, is just about ready to change over. In July, 1932, there were in operation 126 electric locomotives, and this number will be increased to 230 when the extensions now in hand are completed.

Still further extensions are projected: the line going north from Stockholm to Ånge to be ready by the end of 1935, and the line from Gothenburg to Malmö by the end of 1937. The former comprises 380 miles, and the latter 200 miles. With the completion of these two projects the total route mileage electrified will be 1 680 and the number of electric locomotives 325. The electrical system adopted for the extensions now being carried out is the same as that in use on the Stockholm–Gothenburg line, viz. single-phase alternating current at 16 000 volts and $16\frac{2}{3}$ frequency.

Holland.

Following the successful results obtained from the electrification of the Rotterdam–Hague–Amsterdam line, it was decided to extend electric working to the Amsterdam–Alkmaar section and the Uitgeest–Velsen connecting line between this section and the Rotterdam–Amsterdam line. This extension, which includes the equipment of about 30 miles of double track and additional multiple-unit rolling stock, has been carried out, the electric system being, as before, direct current at 1 500 volts.

Russia.

In 1930 certain suburban passenger lines serving Moscow were electrified, using the direct-current 1 500-volt system, the route mileage being 11, and the mileage of single track $27\frac{1}{2}$. Work on a somewhat larger project was begun in 1930, viz. the electrification of a section, 39 miles in length, of the railway from Batum to Baku. The section extends from Sestafoni to Chashuri, and includes the $2\frac{1}{2}$-mile double-track tunnel under the Suram Pass about 140 miles east of Batum. For this scheme direct current at 3 000 volts is employed, and power is obtained from hydro-electric stations in the neighbourhood. The electric locomotives, of which eight have been ordered, are of the type $C_0 + C_0$, having six motors with an aggregate capacity of 2 725 h.p., the total weight, all of which is on the drivers, being 130 tons. Part of the line has already been equipped, and three locomotives have been delivered and are being run for training drivers. Plans have been prepared for the construction of a system of underground railways in Moscow. According to reports in the Press the general plan of the system is a circle with five diametral lines crossing at the centre, the total length being about 60 km.

The second 5-year Plan includes the electrification of several main lines, amounting in all to 18 726 km of route, or about 28 000 km of single track. In addition to these lines, the Plan includes the electrification of about 1 700 km of suburban and health-resort lines.

United States.

Two new suburban electrification schemes were brought into operation in 1931, one by the Reading Co. at Philadelphia and the other on the Delaware, Lackawanna, and Western Railroad, from the New Jersey terminus to Gladstone and Dover. The former is on the single-phase 25-frequency system with 11 000 volts on the contact line, and the initial installation included 70 cars, each being a motor-coach equipped with a pair of 300-h.p. motors. This equipment is sufficient to give an acceleration of 1·25 miles per hour per second and a balancing speed of 70 miles per hour. Each coach is 73 ft. long, weighs 56·5 tons, and seats 86 passengers. Power is purchased as 60 frequency 3-phase current from the Philadelphia Electric Co., and is transformed to single-phase 25-frequency current in a frequency-convertor substation, where it is stepped up to 36 000 volts for distribution by a 3-wire system to 10 auto-transformer substations. The total length of electrified track is 167 miles. Equipments for 30 additional cars are already on order for extensions.

This scheme may be contrasted with the electrification on the Delaware, Lackawanna, and Western Railroad, which is on the 3 000-volt direct-current system. The Hoboken terminus is connected with New York City by ferries and the Hudson tubes. The sections electrified consist of 70 route miles, with a total of about 160 miles of single track. The services provide for 233 trains on weekdays, equivalent to about 23 000 car-miles. Power is purchased from three separate companies, and is transformed in five substations to direct current at 3 000 volts. The whole of the 40 000-kW converting plant consists of mercury-arc rectifiers, of which there are twelve of 3 000 kW and two of 2 000 kW capacity. The rolling stock includes 141 motor-coaches and an equal number of trailers, one motor-coach and one trailer forming a unit. Trains are composed of varying numbers of units up to six. Each motor-coach is equipped with four 235-h.p. motors, which provide for a starting acceleration of 1·5 miles per hour per sec. and a balancing speed of about 65 miles per hour. A 12-coach train has seating accommodation for approximately 1 000 passengers. There are also in service two 3-power locomotives, each equipped with a 300-h.p. Diesel engine and a 360-cell storage battery.

The New York Central Railroad has extended its electrification along the west side of Manhattan Island for freight traffic. For this purpose 42 locomotives, type $C_0 + C_0$, of 2 500-h.p. capacity, have been put into service, and 36 3-power locomotives, type $B_0 + B_0$, each containing a 300-h.p. Diesel engine and a storage battery, in addition to the usual equipment of four 415-h.p. motors.

The New York, New Haven, and Hartford Railroad now owns or operates a total of 868 miles of electrified track. In 1931 this company purchased and put into service 10 new single-phase locomotives, type $2 - C_0 + C_0 - 2$, each equipped with six pairs of motors aggregating 3 440 h.p. The total weight of each locomotive is 180 tons, and the tractive effort and speed at the 1-hour rating are 25 200 lb. and 51·2 miles per hour respectively; the starting tractive effort is 68 500 lb., and the maximum speed is 70 miles per hour.

The electrification of the Cleveland terminus lines was completed in 1930. Trains are hauled into and out of the terminus by 22 locomotives. These locomotives, which are used for passenger service and terminus shunting, are of the type $2 - C_0 + C_0 - 2$, weigh 187 tons, and are equipped with motors aggregating 2 900 h.p., corresponding to a tractive effort of 29 200 lb. at 37·3 miles per hour. A single locomotive will start a train of 1 275-tons trailing load on the maximum grade and the sharpest curve, and will haul this train at 53 miles per hour on level tangent track. The electrical system is direct current at 3 000 volts.

The principal development now in progress is the electrification of the Pennsylvania Railroad from New York to Wilmington, and thence to Washington. When this electrification is completed the Railroad, including the Long Island Railroad, will have 2 210 miles of electrified track, 99 substations with plant of 1 374 500 kW capacity, 1 681 miles of single-circuit transmission line, and 1 686 miles of overhead contact-line; the rolling stock will include 136 electric passenger locomotives, 86 freight locomotives, 98 shunting locomotives, and 1 637 multiple-unit coaches. Except for the Long Island Railroad and the line from Philadelphia to Atlantic City, on which direct current at 650 volts is used, the electric system for this complete scheme is single-phase alternating current at 25 frequency with 11 000 volts on the contact-line.

Special interest attaches to the locomotives for passenger and freight services. The heavy passenger locomotives are of the type $2 - C_0 - 2$ with electrical equipments of six 625-h.p. single-phase motors arranged in three pairs, and connected to the three driving axles through gearing and quill springs. On the 1-hour rating the tractive effort of the locomotives is 26 000 lb. at 54 miles per hour. Each weighs 375 000 lb., the weight on the driving wheels being about 75 000 lb. per axle. They are designed to haul trains of twelve 73-ton coaches at 90 miles per hour, but it is expected that they will be able to deal with trains of 14 coaches, as at 90 miles per hour they are able to exert a tractive effort of 18 000 lb. The motors are of the series commutator type with shunted commutating poles and a comparatively large air-gap. At the maximum speed the armature runs at a peripheral velocity of 12 500 ft. per min., and the commutator at 9 000 ft. per min. The armatures run in roller bearings. The design of the motor has been developed by the engineers of the Westinghouse and General Electric Companies. The same motors are used for the express passenger locomotives, designation $2 - B_0 - 2$, of 2 500 h.p., and for the fast freight locomotives, designation $1 - D_0 - 1$, of 2 500 h.p. The first of the heavy passenger locomotives was ready for final tests on the company's line in April, 1932, and further locomotives were under construction during the latter part of the year. The

company intend to start operation on the New York–Philadelphia section early in 1933.

In New York a new subway is being constructed along Eighth Avenue in the boroughs of Manhattan, Queens, the Bronx, and Brooklyn. Part of this subway is expected to be ready for traffic in the near future, the portion now under construction including more than 200 miles of single track. It is of interest to note that power will be supplied to the third rail from 51 mercury-arc rectifiers, each having a nominal rating of 3 000 kW at 625 volts, with a 100 per cent overload capacity for 5 minutes. In addition there will be 53 000 kW of rotary convertors, which have already been installed in five surface substations. All the substations will be under supervisory control.

Japan.

The most important main line in Japan is the Tokiado line. This connects Tokio with Kobe, via Yokohama, Nagoya, Kyoto, and Osaka. The electrification of the Tokio end of this line was begun in 1922 and by 1928 had extended to Atami, a distance of 65 miles. In 1924 it was decided that the whole line, 370 miles long, should be electrified. From Atami a new deviation 14 miles in length is now being constructed to join the existing line at Namazu. This deviation includes a 5-mile tunnel called the Tanna Tunnel. The new line is to be worked electrically and it was intended to have it completed in 1932. When this has been done the electrification of the western end of this main line, from Otsu to Kobe, a length of 65 miles, is to be taken in hand, to be ready for operation in 1934.

On the main line from Tokio to the west, electric working has been extended to Kofu. On the line from Tokio to the north-west a new deviation is being constructed to the north of Maebashi, which includes the Shimizu Tunnel, nearly 6 miles long, the boring of which was completed early in 1930. It is intended to electrify this new line. Apart from these developments, certain extensions have been carried out on the Tokio City lines.

India.

The extensive electrification scheme on the Great Indian Peninsula Railway in the neighbourhood of Bombay for main-line and suburban services has been completed, and, except for a few in the shunting yards, no steam locomotives have been in use on the lines between Bombay and Igatpuri and Poona since the end of 1930. A full description of this scheme, which includes 571 miles of track, 41 freight and 24 passenger locomotives, 53 motor-coaches and 153 trailers, 15 substations with an aggregate plant capacity of 100 000 kW, 272 miles of 100 000-volt transmission lines, and a 40 000-kW power station, was given in a paper* read before the Institution on the 28th April, 1932.

Early in 1930 the electrification of the suburban line between Madras and Tambaram on the South Indian Railway was completed and the new service was opened to the public. The route mileage is 18½, and the stations are spaced at intervals of about 1½ miles. The electrical system is direct current at 1 500 volts, and power is purchased from the Madras Electric Supply Corporation and is transmitted to two substations. The rolling stock includes seventeen 3-coach units, each consisting of one motor-coach and two trailers, and four 660-h.p. double-bogie locomotives for the haulage of goods trains. In connection with these locomotives, two battery tenders have been provided, each containing a 440-volt battery with a capacity of 158 kWh on the 5-hour discharge rate. These tenders are used to supply power to the locomotives when working in the goods yards, which are not equipped with overhead lines.

* *Journal I.E.E.*, 1932, vol. 71, p. 911.

North Africa.

The electrified system in Morocco, which by the beginning of 1930 included about 160 miles of line, has since been extended by the addition of 35 miles of track. No new substations or rolling stock have been provided.

In Algiers the single-track line from Duvivier to Oued Keberit is being electrified on the 3 000-volt direct-current system. Three substations are being installed, two with two synchronous motor-generators each of 2 500-kW capacity, and one with three similar sets. Thirty locomotives, type C–C, are being provided, each weighing 118 tons. Eighteen of these have already been delivered.

South Africa.

In February, 1932, the line from Maritzburg to Cato Ridge was changed over from steam to electric working. This is an extension of the electrification of the main line in Natal between Glencoe and Maritzburg, with a route mileage of 27 and about 44 miles of single track. Cato Ridge is approximately half-way between Maritzburg and Durban. The extension has required only the track equipment, two new substations, and transmission lines for the supply to the substations from the power station at Colenso; no additional locomotives have been required, as the longer runs enable the existing locomotives to be used to better effect. It was officially estimated that the saving in operating expenses due to this extension of electrification would be £40 000 per annum.

South America.

The final section of the Central Argentine Railway's suburban electrification scheme was completed in December, 1931. This scheme now includes 53 route miles, or 115 single-track miles, all equipped with protected third rail for direct current at 800 volts.

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INDUSTRIAL, AGRICULTURAL, AND DOMESTIC APPLICATIONS OF ELECTRICITY, INCLUDING ILLUMINATION AND TARIFFS.*

By R. Borlase Matthews, Member.

INDUSTRIAL APPLICATIONS OF ELECTRICITY.

Practically all industries, and more especially those concerned with iron and steel, shipbuilding, coal, and textiles, have been seriously affected by the recent general depression of trade, with the result that only a comparatively small amount of new equipment work has been carried out. It is, however, of interest to note that what has been done has been almost entirely in association with electrification. Owing to the shortage of heavy work, the large electrical manufacturing firms are turning their attention to the manufacture of domestic and similar smaller types of current-using apparatus, for which the demand is very rapidly increasing.

Electric Heating.

There has been an improved demand for industrial electric heating equipment. The following are among the new types of apparatus which have recently been introduced.

Immersion-type Steam-Raisers.

Designs of steam-raisers are now available for producing from 35 to 400 lb. of steam per hour. The smaller types are of about 15 kW capacity and are capable of raising steam in from 20 to 25 minutes. They are built for a steam pressure of about 60 lb. per sq. in., and will produce 35 lb. of steam per hour. It is usual for the heating elements to consist of three 5-kW units. The loading of a steam-raiser with an output of about 400 lb. of steam per hour is 150 kW.

High-Voltage Electrode Water-Heaters and Steam-Raisers.

In a recent design of vertical boiler of this type the electrodes are supported by the base-plate and project upwards from it into the shell. Load control is effected by the use of movable shields, the lowering or raising of which over the electrodes lengthens or shortens the path of the current between them. The shields are generally motor-operated, although a handwheel is provided for use in emergency. The standard ratings are 500, 1 000, and 2 000 kW, at 6 000 volts.

Low-Voltage Electrode Water-Heaters.

These are suitable for low and medium voltages up to 650 volts, and for loadings up to 1 000 kW. An interesting feature of one of the latest types of water heaters is that load control is effected by opening and closing hot-water outlet valves, either automatically or by hand. A number of these valves are provided at different levels in the side of the shell. Each outlet-level corresponds to a definite amount of immersion of the electrodes, and when any particular outlet is open (the other outlets being closed) the resultant effect of the water-circulating pump on the one hand, and of the pressure of the steam above the water in the heater on the other, is to keep the water-level at that of the selected outlet. Automatic load-control is usually required, and in the standard equipment the outlet valves are electrically operated and are caused to open and close automatically by means of a differential relay, in order to maintain any desired average load-current.

There is also available a steam-raiser designed for providing small quantities of steam at atmospheric pressure for process work and the like. It consists of a cylindrical outer container into which a tubular-type immersion heater is fitted. On single-phase and direct-current supplies the immersion heater can be arranged to give 3-heat control, thus providing a means of regulating the steam supply. These heaters are made in various loadings, a common size being 900 watts.

Electrically-heated Plattens.

An extension of the application of electric heating is brought about in the heating of plattens for presses, and of hot-plates for tool-heating. The operation of synthetic-resin and similar moulding-presses necessitates the plattens of presses being heated to, and maintained at, a fairly high temperature. Such heating can be conveniently effected by heating elements between the plates of the plattens; the elements used are wire-wound and insulated with mica. Small hand-operated moulding-presses have two electrically-heated plattens, one at the top and one at the bottom.

Power Presses.

In the endeavour to economize time, labour, and money, automatic press equipment has developed considerably. The change from C-frame types to special straight-sided presses has lengthened tool life. Die steels are much improved; better automatic feeding has added safety and accelerated production; the speed of operation has risen materially; and the setting-up time has been reduced. Built-in and individual motor drives increase efficiency by eliminating line-shafting and belting, and also facilitate the straight-line lay-out of machine shops, thus avoiding the necessity for inter-stage storage areas.

High-speed presses make it possible to keep ahead of production schedules. Machines of this kind are available in a variety of types and sizes, adaptable to most requirements, from small models that make 300 to 600

* A review of progress. The last review on this subject was published in the *Journal* in 1927 (vol. 65, p. 351). A review of progress in domestic applications was published in 1930 (vol. 68, p. 147).

strokes per minute up to 350-ton presses that operate at 100 strokes per minute.

Traffic Control.

Great strides have been made during the past 12 months in the manufacture of traffic-control signals. One new type can be used for normal working, as a master controller, as a local controller on a flexible progressive system, or for control by the vehicles themselves. This type has the advantage that it can be installed for normal working and at a later date changed over to flexible progressive working, without the necessity for heavy expenditure or the conversion of equipment.

Synchronous Clocks.

During the past year, controlled frequency has been adopted as the standard practice at the individual main generating stations throughout the "grid" system, for load-control purposes rather than with the idea of providing the consumer with a time-controlled supply. Controlled frequency is thus a by-product of the national scheme. As new sections of the "grid" are completed, the area over which standard time is available expands; thus a new national time system will soon be established.

Considerable progress has also been made in the application of small self-starting synchronous motors to industrial purposes. These include the driving of time-check recorders, charts in graphic instruments, timing devices (both visible and audible), time-interval meters for measuring very short times in manufacturing processes, and testing relays and switches. Motors of this type are also employed for telemetering on the "grid."

Instruments.

The most outstanding feature of the year in connection with instruments is the general employment of moulded synthetic-resin products. Apart from this detail, improvements in existing models have chiefly occupied manufacturers' attention. Rectifier ammeters and voltmeters, which for the first time have enabled direct readings of very small alternating voltages and currents to be obtained, have now reached the stage where they are comparable with moving-iron instruments with spring control. The rectifiers have proved to be thoroughly reliable, and if properly selected they show no sign of deterioration. The application of rectifiers to a.c. recording instruments has resulted in the great advantage of an evenly-divided chart throughout the ranges.

Electric Waggon Tippers.

A new form of electric waggon tipper has recently been installed at a large British colliery. It is of the rotary type and is designed for the automatic clamping and discharging of two 10-ton railway waggons simultaneously. When the waggons are drawn into position the tipper can at once be rotated, as the holding of the waggons to the rails is done automatically during rotation by means of clamping bars and side buffers actuated by the gravity action of the tipping platform and pivoted cradle. The power required is obtained from a single 15-h.p. (1-hour rating) totally-enclosed mining-type reversing motor running at 770 r.p.m., with a flameproof slip-ring cover, directly coupled to spur reduction gearing.

Conveyors and Loaders.

The tendency to-day is to operate conveyors and loaders exclusively by electric motors. In coal mines the gate-end loader is now much more generally used, while conveyors are usually of the belt, drag-link, or jigger type.

Individual Motor Drives.

As an illustration of the modern trend in this direction, it may be mentioned that in a certain recently-constructed motor-car works practically all the machine tools have individual drives. Over 5 000 electric motors were installed for this purpose.

Motors.

Manufacturers have concentrated on improvement in appearance, design, and efficiency of their industrial motors, and, with one exception, there has been no noticeable change or development in the manufacture of electric motors during 1932. The exception is the outstanding advance made in the range of fractional horse-power motors. The range of British motors of this type is now very complete. They include direct-current, repulsion-induction, split-phase, single-phase, and 3-phase motors, which can be obtained in a number of mountings to suit the various types of machines to be driven.

Variable-speed Commutator Motors.

A range of variable-speed commutator motors, though only manufactured by a small number of firms, has been further developed during the period under review. One British firm has manufactured a series-characteristic commutator motor for a speed range of 12½ to 1 (375 r.p.m. to 30 r.p.m.), with constant torque and with an output (varying with the speed) of from 90 to 7½ b.h.p.

Copper-Oxide Dry Rectifiers.

An important application of the copper-oxide dry rectifier has been developed recently in connection with generating apparatus for electrical precipitation purposes. Precipitation plants are used for a wide variety of purposes, and in general involve the generation of a constant or unidirectional voltage of from 30 000 to 80 000 volts. Hitherto it has been the practice to use mechanical rectifiers of the commutator or rotating-brush variety. Such rectifiers are noisy in operation, require frequent attention to the maintenance of brushes or contacts, and have a very low overall electrical efficiency. The new type of rectifier consists of a large number of copper-oxide discs connected in series and arranged in tiers, which are oil-immersed in a tank.

This type of rectifier has no moving parts, and as it is completely enclosed it is protected from dust and damp. The efficiency of precipitation is higher, i.e. higher values of precipitations are obtained, as rectification takes place over the whole of the cycle instead of over a small portion at the peak of the wave, as with mechanical rectifiers. The electrical efficiency of these rectifiers is many times that of mechanical rectifiers. Since most

precipitation plants are in operation continuously, this increase in electrical efficiency is an important feature. It often results in the additional cost of this type of rectification being recovered within 6 months of operation.

Switchgear.

The main activities in this field have been in the revision and improvement of standard products. The extension of the " grid " and the frequency change have temporarily increased the demand for 11 000-volt substation switchgear and pole-mounting switch-fuses. A steady demand continues for inexpensive forms of distribution switchgear for substations in rural and semi-rural areas. For the control of a.c. electric motors, press-button automatic starting and stopping is becoming very popular, owing to its simplicity. This form of starter is usually fitted with thermal-overload and no-voltage devices.

APPLICATIONS OF ELECTRICITY TO AGRICULTURE.

The activities of the Electricity Commissioners and the Central Electricity Board have done much to foster and promote the cause of rural electrification during the past few years. Meetings of the Conference on Electricity Supply in Rural Areas called by the Electricity Commissioners continue to be held at intervals, and satisfactory progress is being made in this connection. The Commissioners have sought expert electrical advice and have also received material assistance from electricity supply undertakings and electrical manufacturers. The progressive extension of the " grid " network is bringing into existence a system which will make the financial results of rural electrification more certain. Evidence of this can be seen in the changed outlook of a number of large supply undertakings, who are now cultivating the rural load much more assiduously. About 50 per cent of the supply undertakings are now authorized to give supplies of electricity for all purposes in rural areas. Many of these have during the last 2 years extended their distribution networks to some of the more rural districts of their areas. About 6 years ago only 600 farms in the whole of this country were receiving a supply of electricity from authorized undertakers. To-day the figure has grown to over 4 000. The fact that there are still 414 000 farms in this country which are not yet receiving a supply means that we are in the unenviable position of having more farms, villages, and country residences out of the reach of public supply mains than any other country in Europe.

The interest which agriculturists are taking in rural electrification was reflected in a recent decision made by the Rothamsted Experimental Station to investigate the numerous possible applications of electricity to farm operations. Their investigations are being divided into the following three groups. (1) To demonstrate the working of appliances which are known to be useful but are not yet as widely used as they might be. (2) To examine critically the devices which are not in common use, but which are expected to have a future. (3) To investigate possible applications of electricity which are not in themselves economical at present.

It is undoubtedly shortage of capital that has caused many farmers to defer wiring their premises and to refrain from purchasing electro-farming equipment. Many would be glad to take advantage of hire and hire-purchase schemes, but unfortunately these are conspicuous by their absence in many rural areas. Reports published by the Electricity Commissioners show that work on both the Norwich and the Bedford demonstration schemes is proceeding satisfactorily. Both schemes cover areas which are almost wholly agricultural, and their success will depend to a very large degree on the development of the farm load. The latter seems to have been neglected, however, in favour of village house supplies. Excellent work has been done by the British Electrical Development Association to popularize the use of electricity amongst farmers, and the displays which the Association has staged at the various agricultural shows have proved an excellent form of propaganda. More especially during the last 12 or 18 months, a large number of supply undertakings have been taking advantage of agricultural shows to bring to the notice of farmers the advantages of electricity. At the last Royal Agricultural Show over 30 well-known electrical manufacturers were represented on the stand of the British Electrical Development Association, and in addition a number were exhibiting on stands of their own.

Electric Light on the Farm.

The latest lighting development has been the extended use of ultra-violet-ray lamps and neon lamps for the treatment of livestock and plants. An objection to the usual type of ultra-violet lamp, so far as farm work is concerned, has been the accompanying mechanism. This difficulty, however, has been overcome in a new type of lamp which can be used simply by operating a switch. In appearance this lamp resembles the ordinary gas-filled lamp, except that at the bottom of the bulb there is a pool of mercury; when the filament is heated, some of this vaporizes and forms an arc between the electrodes, which are situated just above the V of the filament. Another new lamp is one which has been specially designed for lighting poultry-houses during the winter months. This lamp emits light with a spectrum similar to that of sunlight, and the lamp therefore provides a combination of heat and mild ultra-violet-ray irradiation.

Neon lamps are being used to accelerate plant growth in greenhouses. From the latest experiments it would appear that the deep red light emitted by the neon tube stimulates the formation of chlorophyll in the plants, while the absence of excessive heat irradiation prevents the tendency to " lengthy " or " leggy " growth.

New designs of traps for catching moths in orchards and greenhouses are constantly appearing. The most recent is one in which an electric lamp or mercury-vapour tube is surrounded by a series of charged wires alternating with earthed wires, through which a current of about 15 milliamperes at 4 000 volts is passed. The moths fly naturally towards the light, but when they come in contact with the wires they are killed and fall into troughs fixed at the bottom of the apparatus. This ingenious device has been adapted to the purpose of

keeping dairies and byres free from flies. The wires are in this case in the form of a screen, which is fixed in the opening of a window or door. The flies are killed as they attempt either to enter or to leave the building.

Poultry-House Lighting.

In spite of the fact that the lighting of poultry houses has been carried out successfully for some considerable time, it is not yet a common practice throughout this country, although the increased egg production which it renders possible during the winter months fully justifies its adoption. The use of electric light in the laying houses can be adopted not only for increasing the winter egg production but also for promoting the more rapid maturity of table birds. A new and successful feature is all-night lighting for chick-rearing and for 2-year-old layers, which by this means can be made to lay as many eggs in the winter as pullets.

Heating.

Electricity is being extensively used for heating purposes on the farm, more especially for such appliances as incubators, hovers, pig beds, food warmers, and water heaters. Soil heating of market-garden frames by means of electric cables has been definitely proved to have enormous advantages over the old-fashioned manure bed. One foreign firm is manufacturing for this purpose 1 000 000 ft. of cable for sale during the coming season.

Power on the Farm.

The interest which is now being taken by a number of large manufacturing concerns in the application of electricity to agriculture is the reason for the large amount of new equipment which has been marketed during the last 2 years. Agricultural motor units consisting of motors with push-button starters, with plugs and sockets mounted directly on the motor body, are now available. These convenient self-contained units are very easily installed and are transportable. One of the most popular portable designs is the cable-drum type of motor, which first made its appearance on the Continent some years ago. A somewhat similar motor, but with a differently designed and ventilated casing, is now being manufactured in this country. It is known as the " drum " motor, and looks like an all-metal cable drum, the body of the drum being employed for carrying the trailing cable. The motor, which is of 5 h.p., is built inside the drum, and its pulley projects through one cheek of the latter. Collapsible feet are incorporated for holding the unit steady in position when driving. The motor itself is of the simple squirrel-cage induction type. A simple push-button starter is incorporated with the motor and within the drum. The unit is an ideal farm tool which can be transported easily from place to place, even over rough ground, owing to its large-diameter discs.

Another portable motor of recent British design incorporates a novel method of anchoring. The motor is mounted on a 2-wheel truck, and a trail points towards or away from the driven machine according to the direction of rotation. The trail is telescopic, so that the belt tension can be adjusted by means of a ratchet device.

Liquid-Manure Pumps.

A number of ingenious electrically-operated liquid-manure pumps are now available, the latest designs being of the simple submerged centrifugal type. The impellor is used first for mixing and then for pumping the liquid. The efficiency of the best pumps of this type is about 80 per cent. An electric motor of about $1\frac{1}{2}$ h.p. is mounted well above the surface, and the pump is sunk to any required depth.

On the Continent the development of liquid manuring and of the watering of market gardens has now reached such a point that it is becoming quite a regular practice to water-spray farm fields, more especially market gardens and pastures. In this way the farmer can become independent of droughts. The necessary equipment includes motors of about 30 h.p. direct-coupled to multi-stage centrifugal pumps.

Transport.

There are a few installations in this country of pneumatic conveyors for transporting crops about a farm building. This practice will certainly spread as time goes on; it has become an important one on the Continent.

Barn Machinery.

One of the neatest and most compact machines introduced during recent years for use in the farm buildings is an adaptation of the disintegrator to general farm requirements. A machine of this type is now marketed in this country; it can be used for practically all work in the farm buildings, with the exception of chaffing, cattle-cake breaking, and root cleaning. Such a machine overcomes the difficulty of fitting a high-speed electric motor to a low-speed agricultural machine, for the plates of the machine are mounted on the vertical axle of an electric motor of about 1 h.p. instead of on a horizontal shaft. Such machines are compact, and free from gears, friction drives, and belts. They have recently been further adapted so that, where necessary, they can be rendered portable and the motor used for driving other farm machines. As these machines normally have only two speeds, one of 1 500 and the other of 3 000 r.p.m., a detachable speed-reduction box is provided, by means of which six ranges of speed (from 40 to 1 000 r.p.m.) are available when it is desired to drive an existing barn-machine.

Milking Machines.

There has been a rapid increase in the number of mechanical milkers installed during the past few years. A questionnaire recently submitted by the Ministry of Agriculture to the Milk Recording Society showed that more than 50 per cent of the milking machines now in operation on milk-recording farms in this country have been installed since 1928. About 22 per cent of these are driven by electric motors.

Hay Drying.

While progress has in the main been in the direction of smaller machines for use in farm buildings, it is

becoming apparent that, in spite of everything pessimists may say to the contrary, the agricultural industry holds out enormous possibilities as a large power consumer. For instance, developments are now taking place in connection with the installation of large hay-drying equipments in this country. Only a few years ago artificial hay-drying was regarded rather as a protection against bad weather than as an accessory branch of agriculture; but in consequence of the excellent results now being obtained by the artificial drying of lucerne and meadow grass many private firms and research institutes are devoting a good deal of attention to the subject. It is now possible to obtain in this way a concentrated green food which is rich in protein, a very important matter, for we are at present obliged to import a large proportion of the protein-rich food consumed in this country. This question of artificial drying is also of special importance in connection with heavily-manured forage crops, for the full value of the high protein content of such crops cannot be utilized without artificial drying. Within a short time we shall probably see some of these large drying plants in operation in this country, as a syndicate has already been formed for this purpose. Each plant will be equipped with electric motors aggregating 150 h.p., and a crop of about 600 acres will be needed to keep the plant in operation. Harvesting can be carried on throughout the growing season, thus making for factory conditions on the farm. There are about 18 large installations for drying lucerne and grass in the United States to-day. The products are sold to poultry farmers in Europe as well as in the United States.

DOMESTIC APPLICATIONS OF ELECTRICITY.

Each year sees an increase in the total consumption of electricity for domestic purposes. Each month during the year under review the Electricity Commissioners' returns have recorded an increased consumption over the corresponding month of last year. This is entirely due to the increasing popularity of electricity in the domestic sphere, for the severe industrial depression has, in some parts of the country, rendered it impossible for authorized undertakers to maintain their output at last year's level. During the year ended the 31st March, 1931 (the latest period for which complete returns are available), there was a net increase of 545 million units generated, in spite of the fact that in the regional areas of North-East England and Central Scotland there was a falling-off of about 138 million units.

Assisted Wiring, the Hire and Hire-Purchase of Electrical Apparatus, and Tariffs.

As the outcome of recommendations made by the Conference on Electricity Supply in Rural Areas, and after consultation with the representative associations of the electricity industry, the Electricity Commissioners appointed two committees to consider (1) the steps which should be taken to ensure that facilities for assisted wiring and the hire and hire-purchase of apparatus are made available generally, and (2) the various kinds of charges and tariffs offered by undertakers, with a view to making definite proposals whereby a greater measure of uniformity could be brought about. The reports of these committees (presented in June and July 1930) showed that up to the end of the year 1928–29 the number of undertakings which had incurred expenditure on the provision of facilities for assisted wiring was 213, for the hire and/or hire-purchase of apparatus 304, and for both purposes 187. The number of undertakings at this time which had not incurred any expenditure on either was 230. The first committee recommended that all those undertakers who had not hitherto introduced such schemes should be urged to do so. The Electricity Commissioners, acting on this recommendation, have communicated with all undertakings which are not providing these facilities, urging that they should give the subject further consideration and inquiring whether any difficulties stand in their way.

The second committee strongly recommended that a two-part tariff should be offered to consumers as an alternative to the flat rate. As to the tariff which should be adopted, they were unable to point to any basis which was entirely without defects, but they were of the opinion that there was less objection to a domestic two-part tariff, with a service charge based on the size of the house (preferably taking into consideration the outside dimensions) and a running charge per unit for all units supplied. While there is some difference of opinion as to the merits of this proposed tariff as compared with a tariff based on the rateable value of the property, it is of interest to note that many large undertakings are now adopting the size-of-house basis as the fixed-charge part of their tariffs, and it is hoped that many more will soon fall into line. A measure of uniformity on this question of tariffs is long overdue, and its absence is a distinct check to the progress of the domestic use of electricity.

Thanks to the work of these two committees and to the prompt action taken by the Electricity Commissioners, considerable progress has been made with these schemes throughout the country.

Electric Cookers.

Thermal-Storage Cookers.

This type of cooker has been manufactured on the Continent for some time, mainly by municipal supply undertakings. Owing to its high load factor it is a very valuable piece of apparatus both to the electricity supply undertaking and to the users. As long ago as 1926 there were over 600 thermal-storage cookers in use in Stockholm. In this country, however, they were practically unknown until the early part of last year, when one of our largest manufacturers introduced a cooker which utilizes the thermal capacity of a block of cast iron, set in the heart of the cooker and thoroughly insulated against heat losses. A constant input of 500 watts replenishes the stored heat, which can be utilized when required, either by means of the hot-plate or through the oven. The surface of the block projects through a special hob plate of heat-resisting material. Two hot-plates are incorporated which actually form bifurcations of the main storage-block, each hot-plate measuring 7 in. by 4 in. The heating is carried out

by two 250-watt elements, each element being situated under the bifurcations. In the oven, heat is derived from the under-side of the block and is controlled by mechanical shutters operated by a rod projecting through the side. Additional heat can be obtained for the oven from standard elements fixed in the bottom and loaded to 500 watts. A foot-operated change-over switch diverts the current from the block to the oven heaters whenever it is necessary to raise the temperature of the oven for roasting or other purposes. Below the oven a warm cupboard is so placed as to be heated from the under-side of the bottom of the elements. The chief advantages of this type of cooker to the consumer are that the benefits of electric cooking are possible at a predetermined charge, which cannot be exceeded, no matter how carelessly the cooker is used. The cooker is of sufficient capacity for a household of at least six persons. It can be used quite satisfactorily for roasting, grilling, or quick boiling, and it does not necessitate departures from normal methods of cooking. The large heat capacity of the block makes very rapid boiling possible. If the temperature of the cooker rises to too high a value, the excess heat is radiated. The use of a thermostat, a potential source of trouble, can therefore be dispensed with. The advantages of the cooker to the electricity supply authority are (*a*) low maintenance charges, (*b*) continuous load, and (*c*) the fact that it can be installed on any lighting circuit, as the consumption is less than $2\frac{1}{4}$ amperes on a 230-volt supply.

Standard Electric Cookers.

Some time ago a joint committee of manufacturers of electric cookers and of representatives of the Incorporated Municipal Electrical Association prepared a specification for a British Standard Cooker, but, unfortunately, only very few orders have been received. The cooker is made in two sizes, one for six and the other for eight persons. Standardization of this kind is very necessary, and much must yet be done in this direction.

The details of design and finish of electric cookers have greatly improved during the past few years. The majority are finished in non-chipping vitreous enamel. There is still some difference of opinion in regard to the top and bottom heating, as opposed to side heating, of the oven. A large number of ovens are fitted with heating elements at the top and bottom, in others the elements are fitted at the sides and bottom, and a small number have elements at the sides alone. In view of this controversy some manufacturers are equipping their stoves in such a manner that, should a customer prefer it, they can be arranged both for side and for bottom heating. Many manufacturers are using plug-in elements for the ovens, in order to facilitate removal for cleaning. Other improvements include automatic ventilators at the back of the oven, grill-top doors fitted with frictional balance-springs, and larger hot cupboard space. Another detailed improvement, though an important one from the point of view of the housewife, is the practice of rounding off the corners of the ovens so as to make for easy cleaning.

There has also been a marked tendency to introduce a simplified system of cooker wiring. In some cookers the whole of the wiring, and the fuses, switches, etc., are located outside the oven and are immediately accessible by removing the side and back external panels of the cooker.

During the year cooker sales have shown a gratifying increase. One manufacturer reports for the year 1931 an increase in the output of cookers of over 20 per cent over the year 1930, and during 1932 an increase of over 30 per cent over the sales of 1931.

Cooker Control.

A standardized control unit, to British Standard Specification No. 438—1932, is on offer by the leading manufacturers, and this should supersede the many dozen slightly varying types called for by supply engineers.

Boiling-plates.

Though the design of boiling-plates still leaves much to be desired, a certain number of manufacturers have, during the past year or two, introduced considerable improvements. One of the most interesting developments is the introduction of the radiant-type boiling-plate. This consists of a tubular heating-element, arranged as a double coil, hinged to a highly-polished reflector plate. The heating-element consists of nickel-chromium wire embedded in crystalline magnesium-oxide, which has as an external protection a flattened nickel heat-conducting tube. The small mass of the elements, combined with the added advantage of the polished reflector plate, gives exceptionally speedy heating. The coils operate at red heat, thus giving a visible and (to the user) satisfactory indication of heating. The efficiency of this radiant-type boiling-plate is remarkably high. As the heat transfer due to direct contact between the utensil and the coils is aided by radiation and intensified by the presence of the reflector, it is not so essential as with the ordinary type of hot-plate that special flat-bottomed utensils should be employed.

Electric Fires.

In 1927 the present author expressed the view* that the design of many electric fires left much to be desired. Since that time, however, there has been a remarkable improvement, and in many cases there are striking departures from previously-accepted principles.

A very thorough investigation was recently conducted by Prof. S. Parker Smith† into the radiant efficiency and heat distribution of fires. The results obtained showed that the radiant efficiency of the various electric fires tested varied from 55 to 70 per cent. Ordinary electric fires were found to have a radiant efficiency of about 60 per cent, while for bowl types the value was about 70 per cent.

The radiant-heat fire employing a pencil form of element focused in an accurate parabolic reflector of large size, which was introduced a few years ago, has been further improved. The carborundum type of element originally employed has given place to one of nichrome wire wound upon a refractory tube of small diameter, and the chromium-plated reflectors are now being made of brass instead of steel sheet as hitherto. This latter change has resulted in very much better

* *Journal I.E.E.*, 1927, vol. 65, p. 358.

† *Ibid.*, 1930, vol. 68, p. 1211.

lasting qualities, especially where the fire is occasionally used in damp atmospheres.

A number of fires of the flush type are being manufactured for fixing to tiled, marble, or other types of fireplace surrounds. To enable this to be done the backs of these fires are made perfectly flat. Fires for building into surrounds are proving popular where new houses are being built or new tiles or fireplaces are being installed, as they can be built in when the tiles are being fixed. Very striking and pleasing effects are obtained from fires installed in this way, and the trend indicated by this modern tendency augurs well for the future development of domestic electric heating.

Imitation coal and wood fires still retain their popularity. Fortunately the majority of those manufacturers who are interested in this type of fire have not overlooked the importance of providing for the direct emission of radiant heat. Provision is made on a number of small electric fires for carrying out minor cooking operations, such as boiling water and warming food. Fires for this purpose are fitted with flat tops, trivets, or guards. A novel portable fire suitable for hotel bedroom-heating which was introduced a short time ago is fitted with two 1 000-watt heating-elements, one of which is connected direct to the main terminals and the other controlled by a switch on the side of the fire. In the base of the fire a "shilling in the slot" prepayment meter is incorporated.

Panel Heaters.

Recently there has been a marked development in electrically-heated panels. One type of panel heater is composed of a ceramic substance, and contains no metal except the connections. A graphite resistor of ribbon formation is incorporated in the material, the lay-out being so arranged that the resistor covers the maximum amount of the panel. Heating-panels are obtainable in various types for floor, wall, or ceiling mounting. A rather novel use for this form of heating is to incorporate panel heaters in large electric chandeliers. The surface of the panels may be coloured to suit any colour scheme.

Water Heaters.

British manufacturers are now marketing water heaters in many different types, and there is no difficulty in obtaining apparatus to meet practically all requirements. It is generally recognized that electric water-heating is one of the most useful contributions to the labour-saving home, but, owing to the relatively large amount of heat required, electricity can only compete with gas and coal when the charge per unit is relatively low.

Table 1 gives the general average annual consumption of water heaters as at present used.

Table 1.

Size, gallons	Units per annum
$1\frac{1}{2}$	1 100
$4\frac{1}{2}$	1 800
10–12	2 000
20–22	3 000

To electricity-supply authorities the electric water heater is a big source of revenue, and the load is one which many station engineers might make a greater effort to obtain. A number of supply undertakings have developed this class of business; for instance, at the commencement of the year under review there were installed at Croydon 1 882 water heaters, while at Wimbledon 1 744 water heaters were connected.

Excellent work has been done during the year by the Water Heating Committee of the British Electrical Development Association. In June 1931 this Committee drew up a list of recommendations in regard to the design and construction of electric water-heaters, including the standardization of sizes and certain constructional features of such apparatus.

Under most tariffs there is a tendency on the part of consumers to install small-capacity heaters in various parts of the house, e.g. a $1\frac{1}{2}$-gallon heater in the scullery and a 12- to 20-gallon heater in the bathroom. Such a tendency will undoubtedly continue until many more supply authorities throughout the country recognize the advantages to be gained from thermal-storage water-heaters as load levellers. When they do so there will be a much more generous offer of off-peak tariffs to encourage central storage in single heaters of comparatively large capacity.

Refrigerators.

Some progress has been made in the field of domestic refrigerators during the past 2 years, but much more remains to be done. It was recently stated that less than 5 per cent of domestic electricity consumers have

Table 2.

*Revenue from Electrical Apparatus.**

Appliance	Loading	Annual consumption	Rate per kWh	Annual revenue	Annual revenue per kW of demand
	watts	kWh	pence	£ s. d.	£ s. d.
Toaster	500	37	1	3 1	6 2
Iron	600	72	1	6 0	10 0
Vacuum cleaner	200	27	1	2 3	11 3
Cooker	2 500	1 500	1	6 5 0	2 10 0
Refrigerator	300	350	1	1 9 2	4 17 2

* These figures are quoted from the *Electrical Review*, 1932, vol. 110, p. 76.

refrigerators, and there seems little reason to doubt the accuracy of the estimate. There are probably two reasons for this: (1) lack of appreciation on the part of the consumer of the value of refrigeration, and (2) the high cost of equipment. There can be but little hope of the latter difficulty being removed until the former has been tackled. This can only be done by educating the public to the desirability of refrigeration, a task that is being tackled by the British Electrical Development Association. Given an increased demand, there is no doubt that the manufacturers would promptly reduce their prices. Supply authorities will be amply repaid for any effort they make in this direction, for refrigerators provide a very attractive load. Table 2, based on American statistics, gives a comparison between the figures for the revenue obtained from various electrical appliances, and illustrates how valuable is the domestic load.

Miscellaneous.

Electric Irons.

An iron which registers the correct heat for use with different materials has recently been introduced. An indicator, about the size of a penny, is fitted on the top cover of the iron, and is controlled by the expansion and contraction of a bi-metal coil. The indicator has five divisions—for wool, art silk, pure silk, cotton, and starched materials. The latest novelty is the porcelain iron: this is an object of beauty as well as of utility.

Kettles.

New types of safety kettles continue to be produced. In a recent type the safety feature is designed to operate when the kettle is about one-third full. When the kettle is more than one-third full it stands level on the three front feet, but when the contents fall below one-third the kettle tilts backward on to a rear foot; this causes a mercury switch, housed at the bottom of the handle, to operate.

Electric Clocks.

Mains-operated clocks of the synchronous-motor type have been in considerable demand during the past 12 months. This is due largely to the increasing number of a.c. distribution systems which are now time-controlled. There has been some controversy over the question whether such clocks should be self-starting, but it now appears to be fairly generally agreed that in the event of a supply failure it is preferable that a clock should stop until the hands are reset to the correct time, rather than restart when the supply is resumed and show the wrong time. Hand-starting clocks give the user the assurance that when the clock is going it always shows the right time. One large firm of manufacturers propose very shortly to put on the market a self-starting alarm clock, on the principle that if there is a brief failure of the supply during the night it is better for the alarm to sound late than never.

Hand and Face Driers.

These are now being manufactured in wall- and pedestal-type models. These machines are not only more hygienic but far more economical than towels, as they cost practically nothing to maintain and their initial cost is quickly repaid by the saving in laundry bills and towel-replacement charges.

Electric Illumination.

A very considerable change has taken place in this art of late, largely owing to Continental influence. The era of the copying of candelabra and gas fittings has passed. Electric light is now being applied architecturally, as an integral part of the rooms, adding much to the decorative effect. The modern fittings are more in keeping with the recent designs of furniture, which differ largely from the old, owing to the fact that large sheets of plywood that do not warp are now available. It is being more and more realized that glare must be avoided, and that in view of the lower prices for current the wattage per room can be increased. Where bright fittings are desired, chromium and similar non-tarnishing plates are coming into use. In many fittings, beyond a few ornamental nuts, frosted or obscured glass is employed exclusively. Such glass has the advantage of eliminating shadows caused by the fittings themselves. There is an increasing tendency on the part of architects to design the electric illumination features especially to suit the room, instead of selecting standard fittings from a catalogue. Decorative lighting is also employed for overmantels, recesses, corners, and external and false windows. The electrically-illuminated fountain is also coming more into vogue.

Lamps.

Several new types of lamps have appeared, which, though they are not yet on the market, are likely to displace the present type of lamp to a considerable extent, as they give a more uniform distribution of light with an even lower wattage per lumen. These lamps are mainly a development of the neon tube, but they are designed for operating on normal supply voltages.

A sodium lamp suitable for the illumination of arterial and country roads has recently been developed. This lamp has an efficiency for an 80- or 100-watt tube of 70 lumens per watt, as compared with about 12 lumens per watt for the ordinary 100-watt gas-filled lamp.

Accessories.

The tendency for shockproof accessories to replace the metal-covered patterns continues, but certain limitations in regard to moulding insulation materials have yet to be overcome. The tracking trouble limits the application of synthetic-resin products (with either wood or asbestos fillers) to locations where arcing is not present. Certain of the all-white productions have been found unsuitable for many applications, owing to the offensive odours they give off when heated. Further advances in connection with the inherent good qualities of these materials would considerably increase their scope of application by enabling them to replace ceramic and other insulators, which in certain fields are still pre-eminent. A recent development is the introduction of high-temperature-resisting compounds, the need for

which was brought out as the result of laboratory testing of existing moulded accessories.

Plugs and Sockets.

Price reductions for electricity have substantially increased the demand for plugs and sockets, and the general education of architects in this direction which has resulted from the greater demands made by consumers has tended to increase the number of socket-outlet points installed in new houses. There is a distinct trade preference for the adoption of 3-pin plugs and sockets in place of 2-pin.

Fused Plugs.

The introduction of the electric clock has shown the need for a fused plug, a type of product which has for many years failed to secure recognition under the I.E.E. Wiring Regulations. It is also useful for many small pieces of apparatus such as kettles, toasters, and fans. If fused plugs are used the plugs throughout the house can all be of one standard size (say, 15-ampere), yet any small device which is plugged in has its own protection. Various patterns of fused plugs are being marketed and it is apparent that they are here to stay.

Switches.

The loading-up of ordinary lighting circuits by the occasional addition of bowl fires and electric irons connected to the lampholder outlet by means of a lampholder adaptor, has proved the advantage of employing quick-make, quick-break switches for ordinary lighting control; the much greater load-breaking capacity of such switches is an advantage in meeting overload conditions not contemplated when the switches are first installed.

Lampholders.

The use or misuse of lampholders for electric irons and bowl fires has proved the advantage of the solid-plunger type, which will adequately deal with heavy currents. Shockproof-type lampholders are now offered at very reasonable prices, and their widespread use is tending severely to decrease the sale of the ordinary metal types. Home-Office-type lampholders (primarily designed for use in factories) are now entering the domestic field for use in bathrooms and kitchens because of the protection they afford, the reasonable prices at which they are offered, and the inherent advantages that attend their use. The employment of a metal sleeve, either with or without insulation, is now considered essential in connection with shockproof lampholders, to withstand the heat conditions imposed by the use of high-wattage gas-filled lamps.

Fuseboards.

Steel is replacing cast iron, with distinct advantages from the point of view of strength, weight, and minimum breakage in transit and fixing. The Home Office type of porcelain replacement fuse has attained a high degree of success, and the design of this piece of equipment appears now to have nearly reached finality. It has an extraordinarily high load-breaking capacity, so much so that cartridge-type fuses are now somewhat of a rarity in an ordinary installation.

Prices.

The year has seen substantial price reductions, due in the main to standardization and increased demand, which have permitted the manufacturer to proceed with assurance. The economies in production are being passed on to the purchaser.

ELECTRICITY APPLIED TO SHIPS.*

By F. Johnston, Member.

This paper covers the period since Mr. A. R. Everest's review on "Electrical Plant and Machinery, including Marine Applications,"† published in January 1930. The steady increase during this period in the number of motor-ships has, more than any other development, been the means of proving the reliability and the efficiency of electrically-driven engine-room and deck machinery on board both passenger and cargo vessels. The fact that on such vessels steam is not available, except in very small quantities, necessitated the use of electric instead of steam-driven pumps, winches, steering gears, windlasses, etc., throughout. Although this move was originally made with some misgivings in a service which is notoriously, but perhaps rightly, conservative, the results have been such that electric drive has now been extended to both engine-room and deck auxiliaries in steam-driven as well as in motor-driven vessels. This has led to very distinct gains in the all-round efficiencies of recent tonnage. The modern sea-going vessel is just as much dependent on its electrically-driven auxiliaries as on its main engines.

The development of electrically-driven auxiliaries in marine practice has greatly assisted to dispel any fears which may have existed in the minds of shipowners as to the reliability of the electrically-propelled vessel, for in such a vessel the propelling motors and their generators are, on account of their relative robustness, even less liable to give trouble than the smaller auxiliaries on which they are dependent.

Electric Propulsion.

Although electric propulsion has not developed to such an extent in this country as in America, sufficient progress has been made to indicate that it is slowly but surely coming into its own. The chief obstacle which it has to face is that of higher first cost, which, except perhaps for tug boats and ferries, it is difficult to justify on paper. The fact that owners who have once given electric propulsion a trial have invariably continued to adopt it in their new tonnage is ample evidence, however, of its earning capacity.

Electric propulsion gives a comfortable drive, which is appreciated by passengers. As the modern gear-changing car is to the car without gear or clutch, so is electric drive to direct drive in a sea-going ship. The measure of the success of any form of transport is the extent to which it is used by the public, quite irrespective of the thermal or mechanical efficiency of the system employed.

In the period under review the following British-built electrically-propelled vessels have been put into commission: "Strathnaver" (28 000 s.h.p.), "Strathaird" (28 000 s.h.p.), "Monarch of Bermuda" (18 600 s.h.p.), "Rangatira" (13 000 s.h.p.), "Musa" (7 000 s.h.p.), "Platano" (7 000 s.h.p.), "Perman" (2 800 s.h.p.), "Winkler" (2 800 s.h.p.), "Lockfyne" (1 340 s.h.p.), "Cementkarrier" (775 s.h.p.). The total horse-power installed in electric ship-propulsion equipments throughout the world is now well over 1 million.

Supplementary Electric Drive.

Supplementary electric drives, from 1 000 to 1 600 s.h.p., in which exhaust steam from existing reciprocating engines is used to drive a turbo-generator, or turbo-generators, to supply current to a motor or motors on the propeller shaft or shafts, have been installed in several existing vessels, including the "Mooltan" and the "City of Hongkong." In some cases direct current, and in others alternating current, is used for this purpose. This is a method of increasing the efficiency and/or the power of existing tonnage at relatively small cost.

Connected Loads.

The size of the electrical installations on modern vessels continues to increase, and even on moderately large vessels—of, say, 25 000 tons—the connected electrical load is usually from 3 500 to 4 500 kW. In addition to the supply to the engine-room and deck auxiliaries, all of which are generally electrically-driven, there are usually large loads for cooking, heating, ventilating, and refrigerating plants. The standard of lighting has also been raised, and it is now well abreast of the very best practice ashore.

Cables.

Owing to troubles caused by cracks developing in it, lead sheathing has to a large extent been superseded in favour of so-called "hard-rubber" protection in mercantile vessels. This name is a little unfortunate in that one of the principal advantages of this type of protection is that it contains a very small percentage of rubber, and is therefore unaffected by oil vapour and does not readily support combustion.

Cables and wires insulated with this material are clipped up direct to metal trays and to metal bulkheads. They have the advantage of being relatively light, easily handled, and quite immune from damage during erection on board. The disintegration of lead sheathing has been to a large extent prolonged by mixing the lead with small quantities of tin or antimony, or with an alloy of antimony and tin or cadmium and antimony. This material is used by the Admiralty and also on some merchant vessels. Various forms of lead-sheathed cambric-insulated cables have also recently been put on the market for ships' installations, but up to date they have only been used in a comparatively small number of

* A review of progress.

† *Journal I.E.E.*, 1930, vol. 68, p. 139.

ships and to a limited extent. They have the advantage that they can be loaded up to higher current densities than cables with rubber insulation, but care has to be exercised in preventing the ingress of moisture at the ends.

Wireless Equipment.

The principal feature of the last 2 years in wireless telegraphy on board ship has been the steady introduction of interrupted-continuous-wave transmitters in place of spark transmitters. The apparatus now in common use has been developed to meet the requirements of marine work, which are in many respects different from those which obtain in fixed stations. In comparison with fixed stations the number of marine installations is very large and the possible individual earnings very small, so that low first costs and running costs are essential. Again, fixed stations work in pairs on definite wavelengths, and in order to make high-speed automatic working possible a very high degree of stability of wavelength is necessary. This makes it possible for land stations to work continuously with but little separation of wavelength. On the other hand, ship stations are always moving about, and they work either with one another or with coast stations. As accurate and precise tuning is impossible, ship stations work in certain bands of wavelengths and not on definite waves. This permits of the simplification of design. The point to be aimed at is that the transmitter shall adhere to the wavelength on which it begins to transmit. The chief causes of variation of transmitted waves are variation in electric supply, variation in temperature, and mechanical vibration.

Extensive development has taken place during the last 2 years in connection with wireless telephony on ships. This has been made possible by the extension of long-distance wireless telephony to all parts of the world and by the successful development of short-wave wireless communication on wavelengths below 100 m. Marine wireless telephony is now divided into (*a*) wireless telephony over long ranges, up to (say) 2 000 or 3 000 miles or more; (*b*) wireless telephony over shorter ranges, up to (say) 300 to 400 miles for inter-ship communication or communication from ships to special shore stations.

As regards (*a*), the service must be duplex (as in the ordinary land-line shore system), but for (*b*) duplex working is not usually called for, and a switch which will put either the transmitter or the receiver into circuit during the conversation generally meets the requirements. Long-range wireless telephone installations are now installed on all the largest vessels, including the "Majestic," "Olympic," "Leviathan," "Empress of Britain," and "Monarch of Bermuda." Such installations communicate with certain shore stations, such as Rugby in the United Kingdom and Ocean Gate in the United States, from any point on the route of their transatlantic voyages, and during world cruises these vessels have to communicate with fixed shore stations at any time. As regards (*b*), short-range inter-ship telephone services have not so far been in very great demand, except to enable fishing fleets to keep in touch with their parent ship or factory. There are, however, indications that short-distance telephony is growing in importance. An instance of its usefulness was the installation of such a set on the "Britannic" and other Belfast-built vessels for direct communication to the builder's offices during the trials and during the voyage to the destination. Given the demand, a telephone service equal to, and as extensive as, that provided on land is now available at sea.

Direction-Finders.

The frame designs have been improved. Prior to 1929 it was customary to use either large cross loops, the areas being of the order of 120 sq. ft., or exposed wire-wound square loops, on a big framework. The frame has now been reduced to the form of two cross loops at right angles to one another, these loops being approximately 3 ft. in diameter.

Broadcasting stations now form excellent beacons, direction-finder receivers having been designed to incorporate the broadcasting wave-band. The wave-range limit of the modern receiver for ordinary mercantile-marine purposes is 1 600 m.

Gyroscope Stabilizing Equipment.

Numerous attempts have been made in the past to reduce the rolling and pitching of a sea-going vessel. Bilge keels, which consist of fin-like projections attached to each side of the hull well below the water-line, serving to damp down the extent of the roll, are now standard practice. Large tanks on each side of the vessel into which water is automatically forced have also been fitted to a few large liners in order to counteract rolling, but it has only been during comparatively recent years that the gyroscope has been successfully applied for this purpose. A typical example of such an equipment is that installed in 1932 in the 45 000-ton transatlantic liner "Conte di Savoia." There are three gyroscopes on this vessel, one on the centre line, one port, and one starboard. Each weighs 110 tons and is 13 ft. in diameter. Previously this type of stabilizer, with flywheels of some 40 to 50 tons weight, had been chiefly used in pleasure yachts, while one of 62 tons weight was installed a few years ago in a Japanese 10 000-ton aircraft-carrier.

Either a gyroscope can be made to balance the heeling moment of a vessel applied to her by the waves, in which case the equipment is comparatively large, or smaller gyroscopes may be employed to dissipate quickly the energy communicated to the hull by the waves. In the latter case the gyroscopes merely act as dampers. The gyroscope normally spins on a vertical axis, but it is capable of tilting in a fore-and-aft direction. This fore-and-aft tilt is controlled by a pilot gyroscope, which, actuating a switch and geared motor, turns the axis of the main gyroscope in a fore-and-aft direction sufficiently to counteract or diminish the rolling effect of the waves. The maximum range of movement of the axis of the gyroscope in the "Conte di Savoia" is about 60° on each side of the vertical, and the period of the swing set up is from 8 to 18 sec. The reaction couple may be anything up to 3 800 000 lb.-ft., and the force exerted on the bearings up to 100 tons or more.

Depth-Finders.

Several types of instruments are now available for indicating and recording the depth of water below a

vessel, and thus taking the place of the crude lead-line. There are roughly speaking two classes of apparatus now on the market; one uses audible waves and the other a supersonic or inaudible wave.

In the audible type of instrument a transmitter fixed to the bottom of the ship's hull gives accurately-timed taps, which are transmitted by means of a steel diaphragm to the water. The sound travels to the sea bottom and is there reflected back to a microphone, or hydrophone, also fixed to the bottom of the vessel. The function of the instrument on the bridge is to measure the time-interval between the sending-out and the receipt of the echo, and to indicate in fathoms on the scale the depth corresponding to this time. This is done by listening-in by headphones to the combined sounds of transmitted signal and returning echo, the telephones being short-circuited except for this very short period. The time after emission of the transmitted signal at which this period of hearing occurs can be varied by moving a contact around a rotating disc which carries a depth scale.

In the second form of apparatus a wireless transmitter is used to apply an oscillating voltage to a mosaic of piezo-electrically-active pieces of quartz sandwiched between two metal plates fixed to the bottom of the hull, which converts the wave into a supersonic one, having a length of about 4 cm and an average rate of propagation in salt water of 4 900 ft. per sec. The function of the apparatus on the bridge is, as in the audible-sound type of apparatus, to measure the interval of time taken for the waves to travel through the water and be reflected back to the ship's bottom.

In addition to visual and audible types of receivers, there are now on the market recording instruments giving a complete record of the depths of water passed over during the voyage, or of such parts of it as are considered necessary for navigation. For deep-water surveys depths of 4 000 fathoms have been measured in this way by specially-designed instruments, but for ordinary commercial purposes this is quite unnecessary. On passenger ships it is only necessary to be able to measure with accuracy from 2 to 10 fathoms of water under the keel: measurements of depths exceeding 100 fathoms are of relatively small value. For trawlers, depths up to 400 fathoms are important. Most fish are bottom feeders, and the best depth for certain types of fish varies with the locality and time of year. In the modern trawler use is made of the reflected sound in order to find this depth.

Generating Plant.

There is now a very strong tendency to use Diesel-driven generators for lighting and for auxiliary power in all large ships, whether the vessels are steam- or motor-driven. This is done in order to secure the maximum economy, there being no doubt whatever that in relatively small units—say up to 500 kW—the heavy-oil internal-combustion engine is appreciably more economical than the turbine. The waste heat from the exhaust and from the cooling water can, as in the main propulsion units, be used in specially-designed boilers, e.g. the Clarkson type, for giving steam for heating and cooking.

An emergency supply of electricity is now insisted on by the Board of Trade for all sea-going passenger vessels. The generating plant for this purpose is usually worked by an internal-combustion engine, but sometimes by a battery, or by a combination of both. The plant is placed above the margin line, i.e. above the level of the watertight divisional bulkheads. Switching arrangements are generally made to enable the plant to be used in port when the main generators have been shut down for overhaul, repair, or owing to insufficient load. Under emergency conditions this supply is entirely independent of, and disconnected from, the main generators, but under normal conditions it is taken from the main switchboard. Fabricated field-magnets and baseplates are now common, as in land practice.

Switchboards.

Slate-panelled switchboards are giving way to switchboards of the skeleton type, built up of angle iron and having the switches, fuses, circuit breakers, and instruments, mounted on insulated metallic bars. Apart from being very robust, this form of switchboard has the advantage that the attendant can see both sides of it. This is particularly useful during overhaul and inspection.

Switch cubicles with dead-metal fronts are now universal for the control of electrically-propelled vessels, or when for some reason the switchboard has to be placed in a situation where access to it can be obtained by unauthorized members of the crew.

Connections between Generators and Switchboards.

In several of the larger vessels which have recently been built, bare copper bars enclosed in expanded metal trunks have been used for connecting the generators to the main switchboard. These bars are enamelled red, blue, and some neutral tint, to indicate the positive, negative, and equalizing leads respectively. The result is pleasing and is sound mechanically, and the equipment is less costly than insulated and protected cables.

Allocation of Connected Load.

The table on page 144 indicates how the connected load in a modern motor vessel is made up. The figures are for a 25 000-ton passenger ship, equipped with 4 Diesel-driven generators having a combined capacity of 2 000 kW, and a Diesel-driven emergency set having a capacity of 75 kW.

The low-voltage system in such a vessel would be supplied from a motor-generator giving about 15 amperes at 25 volts, and two batteries, each of some 20 cells of the nickel-iron type or (say) 15 of the lead-acid type. This low-voltage supply would feed the following:—

Loud-speaking megaphones to captain's bridge, etc.;
About 20 loud-speaking telephones for navigation;
About 20 automatic telephones for service;
About 56 electric clocks;
About 20 alarm bells and horns;
A luminous bell system of (say) 500 ways;
An ordinary bell-and-drop-shutter system of (say) 700 ways;
Gramophone repeaters with (say) 8 loud-speakers;
Submarine signalling equipment;

Helm indicators;
Electrically-operated thermometers for engine cylinders and refrigerating spaces;
Electric telegraphs;
Wrong-way alarms;
Revolution indicators;
Electric log;
Thermostats throughout accommodation;
Whistle control;
Electrically-operated torsion meter.

Connected Load in Modern Motor Vessel.

Type of equipment	Number installed	Combined load
		kW
3-ton cargo winches	12	317
5-ton cargo winches	4	135
Warping winches	2	115
Capstans	2	189
Windlasses	2	317
Boat winches	20	200
Elevators and hoists	8	26
Gymnasium machines	4	2
Service motors	20	17
Ventilating fans	85	335
Watertight doors	8	8
Steering gears	2	167
Refrigerating compressors ..	2	150
Refrigerating-machine pumps ..	5	31
Refrigerating-machine fans ..	3	21
Emergency plant-cooler motors..	2	4
Engine-room pumps, etc. ..	100	1 160
Cooking equipments	34	999
Water boilers, etc.	21	83
Gyro-compass equipment ..	1	3
Talking-film equipment	—	6
Oil heaters	—	2
Electric heaters	—	270
Electric lighting	—	390
Total load		4 947 kW

Deck Machinery.

Experience has shown that deck machinery must be made absolutely foolproof if it is to survive. This especially applies to cargo winches, which not only have to be used by the roughest of labour in the British and foreign ports of call, but also have to stand up to the brutal usage to which they are subjected by stevedores. Misuse of this kind is fostered by piece work and by the fact that when the stevedore is loading or unloading a hold he is always working against time. The niceties of controller handling are quite foreign to his nature; the controller will be swung hard over from "Off" to "Full on" as quickly as possible, brakes will be jammed on without discrimination, and the winch will be reversed from full speed in one direction to full speed in the other in the shortest possible time. When cargo is being removed from a hold it has often to be dragged along the floor for some distance before plumbing the derrick head, and in this process obstacles are met with which not only put severe strains on the derrick but are also such as to stall the winch. It says much for the design of the modern ship's winch that, despite this rough treatment, breakdowns are now of rare occurrence.

The size of winch most frequently used has a pull of 3 to 4 tons at a rope speed of about 100 ft. per min., increasing to, say, 450 to 500 ft. per min. with light hook. For dealing with the heavier class of cargo, winches of 5 to 7 tons pull are used. The speed rises automatically with the load and an excessive overload brings out the circuit breaker until the load is reduced, when the winch automatically restarts. To prevent the winches overrunning when lowering a heavy load, regenerative and/or centrifugal braking is provided.

The design of warping winches, windlasses, and capstans, must be so arranged that a continuous pull is retained on the rope up to and including stalling point, and in the windlass provision must be made to allow of the anchor coming hard against the chocks when the anchor is weighed. This is accomplished by means of a slipping clutch adjusted to take a sudden blow before the circuit breaker, as determined by the delay action, has had time to act.

Cargo-winch motors are series-wound, so that the speed varies in inverse ratio to the load, and no change gear is required as in a steam winch. The speed range obtained by series winding has not always, however, been found sufficient for modern requirements of cargo handling. Higher relative speeds with lighter loads are obtained by diverting the field winding automatically as soon as the load reaches a predetermined figure, such as that corresponding to 1 ton. An innovation which has been made during the period under review is the fitting of a negative booster or reducer in the base of a deck winch for speed-reduction purposes. This booster is connected across the winch-motor armature, the opposing voltage giving very fine speed-grading. A slight variation of this control is obtained by using a reversing booster, by means of which the speed can be regulated upwards as well as downwards. This leads to some saving in weight and cost. This form of control, as well as the Ward–Leonard system, has also been applied to capstans and windlasses, for which it has considerably greater relative advantages than for cargo winches. The electric winch gives excellent acceleration, a 3-ton load reaching full speed in 1 or 2 sec. after starting, and it requires only about $\frac{1}{5}$ to $\frac{1}{7}$ the fuel consumption of a corresponding steam winch, taking leakage and condensation into account. It also has the advantage that it can be made noiseless.

The use of passenger and service hoists has noticeably increased; as many as 12 to 15 on one vessel are not unusual nowadays. In most passenger vessels of reasonable size, a lift is now provided for taking the engineers from the starting platform in the engine room to their quarters in the boat deck.

The ventilation system now constitutes a very important part of the electrical installation of the modern liner. In the example given on this page of a moderately large cabin class of vessel, it will be noted that there are 85 ventilating fans, the largest of which are 60 in. in diameter and require 50-h.p. motors. Distant control of fans is

now general. The contactor gear is mounted on the back of the motor, and the master controller, which is quite small, is either placed in a convenient position with respect to that part of the vessel where the air is being used, or is grouped with others in central fan-control rooms. Coloured pilot lamps indicate which fans are running, which are dealing with warm air, and which are delivery and which exhaust fans. In modern ships the air is warmed by passing it through banks of steam coils controlled by electrically-operated valves, and these, in conjunction with thermostats placed in the accommodation, keep the temperature constant at the desired value. Air-conditioning plant, i.e. plant for controlling the temperature, humidity, and cleansing of the air, will in all probability soon be installed on every passenger vessel of any pretension. The pumping of sun-baked air loaded with moisture into a vessel does little to add to personal comfort.

In accordance with the latest Board of Trade regulations provision has to be made for closing certain bulkhead doors below the margin line from the captain's bridge, so that in case of flooding, or in anticipation of flooding, these doors can be used to prevent the water from flowing to other parts of the vessel. This was first done hydraulically, but electrical means are now available for the purpose. In the initial stages of development solenoids were used to operate catches for releasing the doors, which then dropped under their own weight into wedge-shaped runways. In modern practice specially-designed geared motors are used to drive the doors, either vertically or horizontally, to their closed positions. The motors continue to run after the openings are closed, and in so doing compress strong spiral springs which give a pressure of about 2 tons on the doors and then operate switches which cut the current off the motors. Coal or other obstructions are therefore forced clear by the V-shaped bottom edges of the doors. An indicator shows the captain the position of each door, and a warning bell is rung automatically for some seconds before the doors start to close. A switch at each side of the door allows the engineer to keep any individual door closed, and another switch enables anyone to open the door from either side of the bulkhead in order to escape from a compartment. This latter switch has, however, a spring return which causes the door to close again as soon as the handle is released.

To replace steam-operated steering gear, two electrically-operated systems are now available, viz. (*a*) electro-hydraulic gear, and (*b*) electro-mechanical gear. The electro-hydraulic type of steering gear incorporates a motor-driven pump of special design which runs continuously while the vessel is in commission. This pump delivers water under pressure to either side of a ram connected direct to the rudder post. In the neutral position the pump simply churns up the water, but when the steering wheel is moved it causes a hydraulic pressure to act on one or other side of the ram, and a follow-up gear actuated by the movement of the rudder again brings the valve mechanism to the neutral position, when the movement stops. In large vessels two pumps are sometimes used, either of which can be put into commission and the other retained as a stand-by, or both pumps can be used simultaneously when quick movements of the rudder are called for. In the electro-mechanical type of steering gear the electric motor works the rudder either through a toothed quadrant, as in the steam steering-gear, or through a worm gear. In the latest form a motor-generator is employed, and this is kept running while the ship is under way. The generator of this set supplies current to the rudder motor, the generator field being supplied with current from an exciter driven off the motor-generator shaft. The field of this exciter is connected across two resistances which form the two arms of a Wheatstone bridge. One of these resistances is placed on the captain's bridge and is geared to the steering wheel, while the other is placed in the steering-gear house and is attached to the rudder-motor shaft. The result is that any movement of the steering wheel causes current to flow in the motor-generator exciter field. This excites the generator, causing current to flow from it to the rudder motor, which in turning actuates the hunting gear attached to the motor and brings the resistance to the same value as that connected to the steering wheel. As soon as this has occurred the motor stops. The adoption of the motor-generator cuts out the contactor control, which in the older forms of this gear sometimes gave trouble.

The recent law which forbids the use of certain preservatives in food has tended to cause an increase in the size of the refrigerating plants on shipboard, and these are more and more frequently driven by electric motors. Negative boosters are sometimes used to obtain the necessary speed regulation, although more frequently this is done by shunt regulators.

Engine-Room Auxiliaries.

A natural consequence of the adoption of motor-ships was the use of electrically-driven engine-room auxiliaries, which have since been more generally installed in steam-driven vessels. The last auxiliary to be driven electrically was the boiler feed-pump; the noisy steam-driven pump is now being displaced by the silent electrically-driven rotary feed-pump. Perhaps the most noticeable change in electrically-driven engine-room auxiliaries has been the adoption of vertical pumps and motors. These take up less floor-space than the horizontal type and also enable the pump impellors to be more readily flooded.

Ball and roller bearings have taken the place of sleave bearings. An innovation which has been adopted by one or two shipowners is the use of one controller for starting up several pumps. This idea has the advantage of saving space and reducing costs.

Cooking.

Electric cooking is continuing to make steady headway on board ship, and it has been adopted on most of the large passenger liners. The upkeep of the modern electric range is less than that of the old-fashioned coal ranges. Progress was at first hampered by the flimsy nature of some of the electric cookers installed. The only serious competitor of the electric range is the oil range, one disadvantage of which is that there is always the danger of the oil vapour flavouring the food. The cost of electric cooking (about ¼d. per meal) is negligible

compared with the total cost per meal, and any difference between the cost of cooking by electricity and by coal or oil fuel is more than counterbalanced by the saving in the weight of the food. The cleanliness, safety, and ease of working obtained in electric cooking are valuable qualities in a sea-going vessel.

Heating.

Apart from air heating by means of electrically-driven fans delivering air through banks of steam coils (see page 145), which is perhaps the cheapest and most efficient way of generally heating a ship, it is now the custom to have individual electric heaters in each cabin. The warm air from the fans heats the vessel as a whole up to, say, 60° F., and any additional heat required can be controlled by the passenger by means of the cabin electric heater. There is a wide difference in the temperatures required by individuals; whereas an American business man may be only just satisfied with 70° F., a young officer in the middle of his army training might feel uncomfortable if the temperature was above 60° F.

Heaters for ships should not be of the red-hot radiant type, or of such design that a passenger can cause a fire by casually throwing a towel or light article of clothing over it. All heaters should also have some visual means of indication to show whether they are switched on.

Electric Clocks.

Owing to the necessity of altering the ship's time periodically during a voyage, most passenger vessels now have electrically-operated clocks installed which can be put "forward" or "backward" as may be required from the chart room. One master clock in the chart room will control, say, 60 secondary clocks, sending out impulses of about 0·25 ampere every minute or half-minute. Each impulse lasts about $\frac{1}{10}$ sec. or less. The current is usually supplied from a small battery, but it is sometimes fed from the ship's supply by tappings off a potentiometer, while in one system the master clock generates its own impulses by a spring-actuated alternator, thus doing away with batteries and all external sources of power.

Luminous System of Communication.

Quick service in the passenger accommodation is of first importance, and this is appreciably assisted by the luminous system of signalling which has been installed in recent tonnage. This system takes the place of the drop-shutter indicators previously installed. The call indicators consist of small lamps, run off the low-voltage supply, one red lamp and one green lamp being placed just outside each cabin. A twin push-button, also coloured red and green, is placed at the head of each berth, the red lamp being labelled "Steward" and the green "Stewardess." The operation of one of these push-buttons switches on the corresponding lamp outside the cabin, and also lights a tell-tale lamp in the chief steward's office, or purser's office, indicating the section from which the call has been made. These lamps remain burning until the steward or stewardess switches them off by a switch situated at the cabin door, either inside or outside the room. This not only ensures that the attendant comes to the correct cabin, but also keeps a check on the time taken to answer a call. When the signal lamps are placed outside the cabin door, the lamps themselves are sometimes used as press buttons for replacing, or extinguishing, the signal light. Direction lamps are also used to show the attendant which side of the ship the call has come from, and to guide him to the cabin.

Torsion Meters.

An important adjunct in the large modern sea-going vessel is the instrument for measuring the shaft horse-power during the trip. An electric torsion-meter is now available for this purpose. This instrument indicates the true mean value of the torque, and operates as follows. The twist of the propeller shaft is used to alter the air-gap in a differential transformer. A second differential transformer contained in the indicator has air-gaps which are alterable by means of a screw micrometer. The cores of the two transformers are excited in series by a current from the ship's mains which is interrupted by a motor-driven circuit breaker. This induces an alternating e.m.f. in the secondary coils. A second circuit-breaker, operated by the same motor, cuts out one half-phase of the secondary current. A unidirectional current indicator is inserted in the secondary circuit, and the two secondary coils of each set of transformers are so connected that their e.m.f.'s are in opposition. If the two sets of air-gaps are of equal length, no current will flow through the indicator. The reading on the drum of the micrometer screw, when the indicator is at zero, is a measure of the twist of the shaft, and therefore of the torque being developed.

Welding.

There has been a considerable extension of the use of electric welding in ship construction. The Classification Societies now allow electric welding instead of riveting in the hull construction, and they have recently issued a set of rules in connection with this practice. It is contended that electric welding reduces cost, saves weight, gives tighter joints, eliminates noise, and gives a better product. Electric arc-welded joints can be consistently made with greater efficiencies in tension, bending, compression, shear, shock, and reversal of stress, than those of riveted joints.

Welded steel is also quickly taking the place of castings for baseplates, engine casings, and similar structures. Considerable savings in weight and cost can be obtained in this way. Arc welds can be made stronger than the material which they join.

The "Fullagar," the first all-welded vessel, was launched in 1920, and she has been in continuous service ever since. In 1924 this vessel went aground with a full cargo on the upper reaches of the Mersey, and was refloated at the next rise of tide. Although strained considerably at low water, she remained absolutely watertight, despite the fact that a large portion of her length at the bilges was set up to an extent of 14 to 15 ft. The turbo-electric ship "Virginia," built at Newport News, contained numerous electrically-welded joints, electric welding having been tried out in a more tentative way on the sister ship "California."

THE ELECTRICAL EQUIPMENT OF AUTOMOBILES.*

By WILLIAM H. GLASER, M.A., Associate Member.

GENERAL PROGRESS.

Since the first review of progress relating to the electrical equipment of automobiles was published in January 1930,† development has been guided principally by:—

(a) the demand for increased interior lighting of omnibuses and coaches, coupled with rigid limitation of the weight of the equipment as a whole;

(b) the application of the compression-ignition engine, more particularly the high-speed type, to road vehicles; and

(c) efforts to improve the rate at which the battery is charged under varying conditions of service.

The result is that we now have larger-capacity dynamos, better starting engagement-gear, more powerful starting motors, a 24-volt system in addition to the 12- and 6-volt systems, more refined dynamo regulators, and a 3-value charging rate associated with the 3-brush dynamo.

Impulse starters are now less widely employed, and their use will probably be abandoned.

Improvements have been made in side and tail bulbs, in lamp mountings, and in ignition systems.

Electric signalling devices have become more general, and their use will no doubt extend steadily; while automatic starting and restarting, and the combined centrifugal and vacuum control of ignition timing, have been introduced.

The better carburation of the modern engine, and the lengthened interval between overhauls, call for higher sparking-plug voltages; and corresponding improvements have been made in the magneto for heavy vehicles.

On the other hand, wire insulation (except in the application of asbestos covering) and permanent magnets show no outstanding progress. In view of the remarkable quality of these items this is not surprising.

Official standardization has made little progress, largely owing to the rapid changes in design. Many British Standard Specifications are under revision, particularly those relating to cables and bulbs. Shaft-end dimensions, and centre-heights, are the most important items in official specifications upon which, at present, a user can rely.

Manufacturers of equipment and of vehicles have, however, with good results co-operated in reducing the number of variations in equipment, even if it is still true that large sums of money could be saved by further advances in this direction.

Wiring diagrams, though differing considerably in appearance on the printed page, will be found upon simplification to show less divergence than they did 3 years ago.

* A review of progress.   † *Journal I.E.E.*, 1930, vol. 68, p. 156.

The position in which the battery is carried, particularly on private cars, is unsatisfactory in some cases, and thoroughly bad in others. Too often the battery is placed inside the chassis frame and underneath the floor boards, with the result that "topping up," checking specific gravity, cleaning, and making sure of tight connections, are tiresome operations. Yet regular attention of this kind is essential, especially when a 3-brush dynamo is fitted, if the life and behaviour of the battery are to be satisfactory. Lack of electrolyte leads to rapid deterioration of the battery and bad starting. Loose connections entail bad starting in any system, but when a 3-brush dynamo is employed they result in a shortening of the life of the bulbs in consequence of the voltage being abnormally increased.

The evil of this position is greater when the wiring is on the earth-return system, as it is on so many private cars. The positive terminal-post is sometimes less than 1 in. away from the frame, or the metal carrier attached to the frame. Corrosion and salting may then bring about a battery short-circuit, which not only leads to bad lighting and starting, but also to a brief battery life. The fact that this particular trouble does not occur very often is no reason why this bad practice should be continued. Since the negative terminal-post never becomes so badly corroded as the positive, it would be an improvement, in earth-return systems, to earth the positive instead of the negative terminal of the battery. This is actually done on some American cars.

Recently certain motor-car makers have adopted the doubtful plan of placing the battery under the bonnet and above the level of the top of the engine. There the battery works in a hot atmosphere which must lead to needless loss of electrolyte, and when it gasses the spray can settle on the engine, sparking plugs, distributor, wiring, control box, and linkwork, and corrode them all. One can only hope that since this practice is confined to the smaller cars the bonnet ventilation will prove adequate to ward off the worst dangers.

Low-tension wiring tends to be arranged on the earth-return system on private cars, and on the insulated-return system on heavy vehicles. The use of wiring in harness or loom form is general on private cars, but not yet on heavy vehicles.

The amount of wiring inside the steering column has been reduced to a minimum by fitting all the switches, except the horn and dipping switch, at the foot of the steering column. Also the wiring of the side lamps under the mudguards is now often carried inside, and protected by, a stay—a welcome, if belated, improvement.

DETAILED PROGRESS.

The first review of progress‡ traced the development of electrical equipment from the beginning, and drew

‡ *Loc. cit*

attention to the important influence of the battery upon design. This influence is still one of the guiding features. The dynamo field-switch has become a 3-position switch, controlling the dynamo in such a way as to give full output only when the lights are in use, and leaving the driver to select one of two reduced outputs when they are extinguished. This switch is used only with the 3-brush type of dynamo. A 2-value charging rate for use when the dynamo is fitted with a regulator will be described later (see page 152).

The electrical equipment of automobiles is now so highly specialized that it is profitable to regard it not only as an assemblage of units but also as an assemblage of systems, which can be described as follows:—

(i) Battery, dynamo, bulbs, accessories system.

(ii) Battery, starting-motor, engine engagement-gear system.

(iii) Battery and ignition coil (or magneto), distributor, high-tension wiring, sparking-plug system.

(iv) Battery, heater-plug system.

(v) Low-tension wiring, fuses, switches, cut-out system.

Omnibuses and Coaches.

It will be convenient first to describe progress in connection with heavy-vehicle equipment in British practice, and afterwards to direct attention to differences in foreign practice and in the equipment of private cars.

(i) *Battery, Dynamo, Bulbs, Accessories System.*

Ten years ago the normal lighting equipment of a typical public passenger-carrying vehicle consisted of a pair of 12-volt dynamos coupled in parallel to a lead-acid battery of 110 ampere-hours capacity (at the 10-hour rate) with a total lamp load of 16 amperes. The control board contained two cut-outs (reverse-current relays), one for each dynamo. Each dynamo had a maximum output of 12·5 amperes at the mean working temperature, and gave this output at about 2 000 dynamo r.p.m., corresponding to a road speed on top gear of about 20 m.p.h. The battery therefore supported the lamp load at the 7-hour rate, and the maximum dynamo output was 56 per cent in excess of the lamp load. The dynamo supported the lamp load at 1 150 dynamo r.p.m.

Three years ago the normal equipment was a single 12-volt dynamo, $6\frac{1}{2}$, 7, or 8 in. in diameter, with a lamp load of 25, 38, or 48 amperes, which was supported at 950, 1 100, or 900 dynamo r.p.m. The battery took the lamp load at about the 5-hour rate, and the maximum dynamo output was 33, 33, or 25 per cent respectively in excess of the lamp load. Maximum output was obtained at 1 150, 1 200, or 1 000 dynamo r.p.m., corresponding to road speeds on top gear of the order of 14 m.p.h., the lamp-load output being obtained at about 12 m.p.h.

To-day these selfsame equipments are used, but a much more powerful one has recently been added, in which the lamp load is 38 amperes at 24 volts. This output is obtained at 900 dynamo r.p.m., and the full output of 56 amperes at 1 000 r.p.m. The battery supports the lamp load at about the 6-hour rate. The dynamo is 8 in. in diameter, and weighs no more than the 8-in. dynamo of 3 years ago, although its output is at least 50 per cent greater. The lamp load could be increased safely to 42 amperes. This dynamo is fan-cooled, and has light alloy end-shields.

It will be seen that the trend of progress has been to lower the dynamo working-speeds. Although this adds to the weight of the dynamo, it increases the time during which the battery is charged, and therefore enables a smaller battery to function satisfactorily, with an overriding saving of weight.

The dynamos of 10 years ago were rectangular, 2-pole machines, regulated by armature reaction, which was assisted by a pair of regulating poles in addition to the main poles, the voltage being controlled by the battery. These dynamos, which are belt-driven, can still be seen under the radiators of the older London omnibuses.

One of the disadvantages of a dynamo controlled by armature reaction and a battery is that the current is to a considerable degree independent of the state of charge of the battery. Consequently, if the running schedule involves only a small proportion of lighting time, or standing time, the battery may become overcharged and deteriorate rapidly, while owing to the high voltage the bulbs are liable to have an unduly short life. Accordingly, in the equipment under consideration, the control gear included a switch for cutting out one dynamo at will—for instance, during the summer. The dynamo output at any speed is by this means reduced to one-half.

The battery capacity was so chosen as to avoid as far as practicable any noticeable fall in the brilliance of the lamps during long halts. Halts of half an hour at the end of a journey were not unknown in those days. The large capacity of the battery, however, greatly facilitated the regulation of the dynamo.

Seven years later, i.e. 3 years ago, the range of types of passenger-carrying vehicles had widened. The lamp load varied from 25 amperes to 48 amperes on a 12-volt circuit. The dynamo was a totally-enclosed plain shunt cylindrical machine, of the wave-wound 4-pole design, controlled by a field-excitation regulator instead of by the battery. Further, running schedules had been speeded up, and long halts had been abolished. In addition, starting motors and alkaline batteries were beginning to be fitted.

The battery capacity was now determined by the lamp load, the charging requirements, and the current taken by the starting motor (where one was fitted). Experience showed that satisfactory results could be obtained with a battery of the lead-acid type having a capacity which enabled it to carry the lamp load at the 4- to 6-hour rate, or with one of the alkaline type which would carry the lamp load at the 3- to 5-hour rate.

During the last 3 years it has come to be clearly recognized that good lighting attracts passengers, who have taken their standard of lighting from brilliantly-lit tramcars and tube trains. Lamp loads have therefore increased; the latest double-deck covered-top omnibus has a lamp load of 38 amperes at 24 volts (the nominal value).

The battery fitted to this vehicle is either of the lead-acid type with a capacity of about 200 ampere-hours, or of the alkaline type with a capacity of about 160

ampere-hours. The dynamo is fan-cooled, 8 in. in diameter, and weighs about 110 lb. It gives its full output of 56 amperes at 1 000 dynamo r.p.m.

Satisfactory characteristics for the dynamo of an omnibus or large coach have been shown by experience to be as follows: cutting-in speed, 600 r.p.m.; lamp-load speed, 900 r.p.m.; full-output speed, 1 100 r.p.m. ($1\frac{1}{2}$ times engine speed). The machine must be capable of running continuously at 3 500 r.p.m., and for short periods at 5 000 r.p.m., under full load without injurious sparking. Further, the full output should exceed the lamp load by 25 to 35 per cent.

The dynamo of to-day complies with all these requirements, and is capable of running 20 000 miles without attention. For omnibuses and coaches it is now invariably of the regulator type; indeed, it is doubtful whether a dynamo regulated by armature reaction and a battery could be designed to give the characteristics mentioned, within the present weight limitation.

Regulators.—The field-excitation regulator is of either the single-pair or the double-pair type. In the one type there is a single pair of contacts operated by the armature of an electromagnet. The contacts are in the field circuit of the dynamo, and are bridged by the field resistance. Consequently, as the contacts open and close they switch the field resistance into and out of the field-winding circuit.

In the other type there is a similar pair of contacts performing the same function in the same way, but the field resistance is lower. The armature operates a second pair of contacts, the closing of which completely short-circuits the field winding and connects the field resistance in series between the dynamo brushes. Over the lower part of the speed range, or the heavier part of the load range of the dynamo, the regulation is effected by the first pair of contacts, which separate only by minute distances of the order of 0·001 in. With the transition to the higher part of the speed range, or the lighter part of the load range of the dynamo, the regulator armature moves nearer to the core by several hundredths of an inch, and regulates the dynamo by periodically short-circuiting the field coils as described above.

The core of the electromagnet in both types carries two coils which provide the excitation; the one is a pressure coil connected across the main terminals of the dynamo, and the other is a current coil in the dynamo-battery circuit. The coils are wound and connected so that they assist one another in magnetizing the core when current flows from the dynamo to the battery and load. The current coil is shunted in some regulators.

Since a definite excitation is needed to operate the armature, any fall in voltage is compensated by a rise in current; and thus the lower terminal voltage of a partly discharged battery, or of one on to which a heavier load has been switched, automatically results in a higher charging or load current. Conversely, as a battery becomes more highly charged it receives a smaller charging current.

Some 6 years ago the type of regulator most widely used on commercial vehicles was of the single-pair form. Although it was satisfactory in performance, it handicapped the dynamo designer because it limited the maximum field current to about 1·4 amperes. By 1930, regulators of the double-pair type were becoming more widely used, because they enabled the field current to be raised to 2·4 amperes. During the last 3 years double-pair regulators have gradually displaced the earlier type. Quite recently, however, the single-pair type has been redesigned, and it will undoubtedly displace its forerunners within the next 3 years. This forecast is made on the grounds that the single-pair regulator is of simpler construction, more robust, and able to deal with an intermediate value of the field current. Further, the field system can be split and controlled by two such regulators, one in each half of the field winding. The total field current thus obtained is higher than has ever before been possible in a motor-vehicle regulator dynamo. A further development of the regulator is described on page 152.

Bulbs.—There has been no change in the standard headlamp bulb during the last 3 years. It is a gas-filled bulb of 24 or 36 watts rating. Now, however, side, tail, and dashboard bulbs are also of the gas-filled type, in order to diminish blackening. The efficiency of the 6-volt 3-watt bulb is a trifle lower than that of the vacuum type; but its superior intrinsic brilliancy, and its freedom from blackening, more than compensate for this.

The increased output of dynamos, and the high output required from starting motors for compression-ignition engines, have led to the introduction of a 24-volt system. This presents no difficulty except with regard to headlamp bulbs, which are at present difficult to manufacture with a filament sufficiently closely bunched to give a well-formed beam. The obvious method of overcoming this difficulty is to use two 12-volt bulbs in series, and this is satisfactory technically except when it is desired to avoid dazzling by dipping one beam and extinguishing the other. Some long-distance coaches, accordingly, now have the headlamps wired on the 3-wire system, which enables two 12-volt bulbs to be used in series, and one to be extinguished while the other is dipped. The use of bulbs of different voltage ratings on the same vehicle may, however, be regarded as a drawback by some operators.

Dazzle problem.—Two methods have been successfully used to avoid dazzle. In Britain the most widely adopted is that of dipping one beam and extinguishing the other, and this method has the advantage that the dipped beam is a useful aid in keeping a track in open country.

The other method is to use a double-filament bulb. In Britain and on the Continent the most favoured type of bulb is that in which the dipped beam is obtained from a filament situated in front of the main filament, and having the lower half of its light stream cut off by an opaque screen. The main filament in these bulbs is V-shaped.

Other types of double-filament bulbs are those which have two V-filaments arranged in planes at right angles to each other. In one type the filament in the vertical plane is rotated sideways in order to produce a sideway deflection of the dipped beam.

The American double-filament bulb has two V filaments in parallel planes a few millimetres apart, and the reflectors are not simple parabolas, but are shaped to modify the light distribution in a suitable manner.

The double-filament method of producing a dipped beam has the advantage over the swivelling reflector or lamp of giving a better driving light when the beam is dipped; but it does not help the driver to keep a track in open country. Nevertheless, the double-filament bulb is certain to prove a serious competitor of the dipping lamp or reflector.

Fog lamps.—Recently a fog lamp fitted with a bulb having a single hooded filament has been introduced. An adjusting device outside and at the back of the lamp enables the width of the beam to be set to suit the density or structure of the fog.

Lamp mountings.—In order to increase the length of life of headlamp bulbs subject to severe vibration, such as inevitably occurs on some types of heavy motor vehicles, the headlamp is mounted on a two-part stem. The lower part of the stem is fixed to the chassis, and the upper part to the lamp. The two halves telescope into one another, and are united by a rubber cylinder situated between the telescoped parts.

(ii) *Battery, Starting-motor System*.

Many omnibuses and coaches are now fitted with starting motors. Three years ago this item of equipment was rather the exception on commercial vehicles. The gear ratio of the starter drive is between 10 : 1 and 25 : 1. In Europe the lower gear ratios are the more common, an average value being 11 : 1. In America and Canada starting motors are often fitted with gearing between the armature shaft and the pinion, thus giving an overall speed reduction, from armature shaft to engine shaft, of as much as 25 : 1. The average value is 23 : 1.

Within the last 3 years the 24-volt starting motor has been developed in Europe to cope with the high-speed compression-ignition engine. This motor is capable of developing on the engine shaft an initial torque equal to, or even greater than, the maximum torque which the engine itself can develop. In America a 12-volt starting system is used, two starting motors being geared to the engine flywheel for heavy duty.

In Europe the size of starting motor usually fitted is 6 in. in diameter and about 65 lb. in weight. With a 12-cell lead-acid battery of 110 ampere-hours capacity (at the 10-hour rate) such a starting motor will take nearly 1 000 amperes at the moment of switching on, and will develop an initial torque of about 45 lb.-ft. at its pinion. As the engine speed increases, the starting-motor torque and current fall. Average values for a starting motor cranking a high-speed 6-cylinder omnibus oil-engine at 5° C. are 30 lb.-ft., 900 r.p.m., 700 amperes, 12 volts. A rise in temperature of only a few degrees permits a higher speed, with a lower current consumption.

The greatest difficulty in applying a starting motor is to devise a satisfactory engine-engagement and driving gear; in this connection two interesting advances have been made since 1930. The difficulty is to avoid damage when meshing the pinion, or in the event of backfiring or rocking, or when the engine overruns the starting motor upon firing. The danger arises from high acceleration—of the starting motor (if started without load) and of the engine (particularly of the high-speed compression-ignition type) when getting under way. While the loose-pinion, screwed-quill, inertia engagement-gear is still the one generally employed in private-car equipment, and is still extensively applied to heavy vehicles, the high accelerations just referred to have led the designer to try other forms of engagement-gear, with a degree of success which makes it likely that they will survive for a considerable time.

In one type of starting motor a 2-stage solenoid starting-switch is incorporated; and the armature core is out of register with the pole shoes. When the starting button is pressed the first pair of contacts of the solenoid switch close, and the armature rotates relatively slowly (100 to 300 r.p.m.) and slides forward. If the pinion does not mesh at once, the slow rotation continues until it does; and when the pinion is well in engagement the forward movement of the armature operates a trip which allows the second pair of contacts to close, and apply full power to the starting motor. In this way the starting motor is engaged without damage. To safeguard the starting motor when the engine overruns upon firing, and to protect it against the high acceleration or shock of a backfire, a multiple-plate friction clutch is incorporated in the transmission gear in the starting motor. The outer plates are backed by a ring, and the inner plates are mounted on a sleeve. This clutch is tightened by the pinion reaction applied through a quick-thread screw in the sleeve. The ring abuts on the circumferential parts of a disc spring, which is in turn supported near its centre. When the engine overruns and the pinion reaction vanishes, the clutch acts as a free-wheel. At the same time the fall in the starting-motor current lowers the solenoid action of the field system on the armature core, and the armature slides out of mesh under the pull of a return spring. Should a backfire occur, the pinion reaction rises above the normal value and the spring disc is bent further than when the clutch is merely driving. The screw is, in fact, tightened so much that the sleeve presses against regions of the disc between its centre and circumference, and thus bends it until its circumference leaves the ring. In this way the clutch plates are temporarily freed from pressure, and again act as an overload free-wheel.

The second improvement has been applied directly to the screwed-quill, loose-pinion inertia engagement-gear. The helical transmission spring has been omitted and in its place a multiple-plate clutch, which carries the pinion, serves to absorb shock; but it is also used to transmit all power. This clutch is spring-loaded under a constant thrust, which is high enough to enable the clutch to transmit the maximum starting-motor torque without slipping, but low enough to allow the clutch to slip in the event of a backfire. To avoid damage when the pinion teeth strike the flywheel, and to facilitate quick meshing under this condition, the screwed quill is splined to the driving shaft and is backed by a helical spring. Thus, when tooth strikes tooth the blow of the heavy clutch is partly cushioned by the helical backing spring, and the thrust on the pinion remains low enough to permit continued rotation. Further, when tooth comes opposite gap, the pinion shoots into mesh under the pressure of the spring. When the engine overruns upon firing, the acceleration

is high enough to throw the pinion out of mesh by making it unscrew in the manner well understood. A similar backing spring is fitted to the starting motor with the overload release clutch, with similar objects.

The starting of the compression-ignition engine, particularly the high-speed type, presents two difficulties not encountered in the starting of a petrol engine. When the engine is cold, or if the fuel-feed system is not properly primed, the engine may have to be cranked for a considerable time, of the order of 100 or even 200 seconds. Consequently the starting motor must be designed to have its commutator, brush gear, and current consumption such as will prevent overheating and rapid brush wear. These requirements have been satisfactorily met. Again, a compression-ignition engine will sometimes fire weakly on several occasions before it finally gets away; and so high is the acceleration which these engines develop that they are apt to throw a screw inertia pinion out of mesh before they are firing properly. This difficulty has been met by choosing a starting motor with correspondingly high acceleration characteristics.

Since 1930, the alkaline nickel-cadmium battery has been applied with increasing success to the starting of heavy vehicles; but it has been found advisable to use a 10-cell battery for a nominal 12-volt system, instead of the standard 9-cell battery which suffices for lighting.

Double-voltage regulator.—A 10-cell alkaline battery in a high state of charge may develop 16·5 volts across its terminals when it is being charged, and such a voltage is apt to shorten the life of the bulbs, particularly as it may be maintained for some time when only side, tail, and destination lights are in use. To meet this contingency, the double-voltage regulator was introduced. It is now always installed in conjunction with a 10-cell alkaline battery. This regulator is of the double-pair type, with an additional voltage coil which is brought into operation in parallel with the usual voltage coil by means of a master switch in the lighting circuit. An alternative plan is to take a tapping off the temperature-compensation resistance of the usual voltage coil, and to short-circuit part of this resistance by means of the master lighting switch. The same methods of dealing with a double voltage are applied to the new single-pair regulators.

(iii) *Battery and Ignition Coil (or Magneto), Distributor, High-tension Wiring, Sparking-plug System.*

The energy of the discharge in the ignition system bears no direct relation to the energy required to ignite the explosive charge. The latter is a small quantity; the electrostatic energy stored in the capacitance associated with the sparking plugs and cables, when these are charged to the sparking voltage, suffices to ignite any effective mixture. Additional energy is, however, desirable to burn off oil which may collect on the plug electrodes; but still more is necessary to supply leakage across carbon deposits when running, or moisture deposits when starting.

In a coil-ignition system the total energy of the spark diminishes as the speed of the engine rises, whereas in a magneto system it increases. The problem is, therefore, in the coil to provide sufficient energy at high speeds without overheating the coil at low speeds or when it is accidentally left in circuit with the engine stopped; and in the magneto to provide sufficient energy to enable the engine to be started at low speeds, without burning the electrodes at high speeds.

During the last 3 years, advances have been made in design and construction which enable manufacturers to offer thoroughly satisfactory ignition coils and magnetos. This has been done in the coil by a judicious choice of the degree of coupling between the primary and secondary windings; and in the magneto by adopting the rotating-magnet fixed-armature construction, which leaves room for ample insulation and provides sufficient armature reaction to limit the energy advantageously at the higher speeds.

(iv) *Battery, Heater-plug System.*

The material of which the heating elements of a compression-ignition engine heater-plug are constructed must be sufficiently heavy to resist being burned away or blown to pieces by the turbulent combustion. They are therefore made to work at 2 to 4 volts. They may be wired in parallel or in series: parallel wiring is preferred, since in this case the failure of one plug during a critical start puts only one cylinder out of action.

In some installations one of the starting cells is used for heating the plugs; in others a separate heating battery is installed, which is charged, through a resistance, in parallel with the starting and lighting battery. The latter method has the advantages that the capacity of the heating battery may be higher than that of the main battery, and the full voltage of the main battery is available for starting. On the other hand, the former method saves a little weight.

(v) *Low-tension Wiring, Fuses, Switches, Cut-out System.*

The principal progress in connection with this part of the equipment has been the increased use of solenoid-operated starting switches. The use of such a switch shortens the length of cable in circuit with the battery and starting motor, and the reduced loss improves the starting effect.

Fuses, hand switches, and the cut-out, have been improved in details, one common object being to reduce the voltage-drop to a minimum. In fact, the voltage-drop has now been reduced, intentionally, to such an extent that the low-tension wiring should be explicitly specified. If the drop between the dynamo and the battery exceeds 1·5 volts in a regulator equipment, the charging characteristics may be upset.

In a regulator system a battery in a low state of charge receives a heavy charging current—in order to remove it from, or prevent it sinking into, the danger zone of sulphation. A well-charged battery, on the other hand, receives a charge at about the 20-hour rate, to avoid needless waste of electrolyte. This distinction depends upon the difference in the battery-terminal voltage, a difference small enough to be seriously interfered with by variations in the voltage-drop of a wiring system of too high resistance.

Lorries.

The problem peculiar to the lorry is set by the large size of the battery necessary when a starting motor is

fitted. The battery capacity is determined solely by the characteristics of the battery-starting motor system, since a lorry large enough to justify the fitting of a starting motor is still amply served by equipment requiring only 7 to 11 amperes at 12 volts, apart from the starting current. Were it not for starting requirements, a battery of about 50 to 70 ampere-hours capacity, depending upon the proportion of standing time to running time, would suffice. For starting, however, a larger battery is desirable; and it must be large enough to start the lorry engine in very cold weather. In summer the lorry may run for several months without needing the lamps, and with a minimum drain on the battery for starting purposes. In such circumstances there is great danger of losing more electrolyte than is realized, by long-continued charging. This difficulty has been met by refinements in the adapting of the regulator characteristics to the requirements of lorry service.

Combined regulator and cut-out.—Another difficulty is to keep the price of the equipment down to a suitable level. In this connection an ingenious double-pair regulator is available which acts also as a cut-out. Hence the armature operates no less than three pairs of contacts. Of these, two pairs serve to regulate the dynamo, and they act exactly in the manner described for the two-pair regulator. The cut-out contacts are arranged to close under spring action, and are held apart by the armature until it is attracted towards the core. When this happens the armature—in moving forward—first allows the cut-out contacts to close, thus completing the circuit between the battery and the dynamo. It next operates the field-resistance contacts, of which one is spring-carried; and ultimately, under appropriate conditions, regulates the dynamo by the field short-circuiting contacts.

One of the cut-out contacts is mounted on a bimetallic strip, which serves the purpose of, and saves the fitting of, a main fuse. Should the main current become dangerously high, the bimetallic strip becomes hot enough to bend sufficiently to reopen the main circuit. Of course, when the strip cools again it closes the circuit, but if a dangerous current still flows the action is repeated. In practice this combined regulator and cut-out has proved to be reliable for a lorry equipment. It is used in very large numbers on private cars and on motor cycles on the Continent. It is appreciably cheaper than a separate regulator, cut-out, and main fuse.

Private Cars.

The electrical equipment of a private car differs in the following particulars from that of a heavy vehicle. The dynamo is of the 3-brush type in British, Canadian, and American practice. Continental cars, however, are often fitted with a regulator dynamo, the regulator and cut-out usually being of the combined type. The 3-brush dynamo has a 2-stage resistance in its field circuit. When the lamps are switched on all the resistance is short-circuited; but when they are off the driver can select either of two charging rates by means of a 2-position switch, which is usually combined with the lighting switch. Thus the driver can adjust the battery charging-rate to suit his running schedule.

Starting motors on British private cars have the loose-pinion, screwed-quill inertia engagement-gear; some Continental cars, and more Canadian and American cars, are fitted with a sliding engagement-gear, which is pushed into mesh by hand or foot operation. A free-wheel, often of the roller-clutch type, is fitted, and comes into action when the engine overruns. The battery is of the lead-acid type.

Ignition is almost always by coil, the battery having become reliable, and to a considerable extent protected from abuse by the 2- and 3-value charging-rate switch, and by the improved carburation of the present-day engine. An additional, powerful factor is, of course, the lower price of coil-ignition equipment, made still more attractive by the easier task of arranging a drive for a distributor only.

Automatic starting and restarting of the engine have just been adopted on British cars. The engine starts when the ignition is switched on, and restarts after an accidental stop. A time-lag element, however, delays the restarting for 1 sec., to give the engine time to come to rest. For if the engine happens to run backwards and the pinion is then meshed, a bent shaft, or broken spring, is almost certain to be the result. A further safety device is a bimetallic strip which switches the current on and off, and so causes the automatic device to click audibly and repeatedly, if for any reason the engine does not turn when it should. This warns the driver to switch off the starting current.

Occasionally a dynamotor is fitted to a private car, but this is done less frequently than it was 3 years ago. The difficulty is to provide a sufficiently high starting torque, and a low enough full (dynamo)-output speed with a practicable gear ratio. In the past a 2-speed gear was sometimes incorporated, but in at least one present-day equipment a solution has been found by working the dynamotor as a 24-volt starting motor and as a 12-volt dynamo. At starting, the halves of the battery are connected in series by a series-parallel starting switch. In this equipment the dynamotor is direct-coupled to the engine shaft.

In Canada and the United States, ignition timing is frequently controlled by a distributor which is operated both centrifugally, according to the engine speed, and by vacuum, depending upon the suction in the induction pipe. Thus the timing of the spark is made to depend not only on the speed of the engine but also on the throttle opening. The method is said to give reduced petrol consumption and better slow running. It is likely to be introduced into Britain.

In conclusion, the author wishes to express his gratitude to his colleagues, and to Mr. G. Chelioti, for the help they have given him in the preparation of this review.

ELECTRO-PHYSICS.*

By NORMAN R. CAMPBELL, Sc.D.

MEASUREMENT AND TECHNIQUE.

High-speed Particles.

Lord Rutherford's work on artificial disintegration suggested that the best way of getting information about the structure of the atomic nucleus would be to bombard it with particles able to penetrate to its interior. It suggested also that such particles would need to be generally similar to α-rays, being of atomic mass and having kinetic energies of not less than 3 million electron-volts. Both the quantity and the quality of α-rays are very limited; they are all helium nuclei, and 10 grammes of radium would barely provide enough α-rays to carry a current of 1 μA, even if none were absorbed in the emitter; the artificial production of similar particles in greater variety and abundance is therefore desirable. The problem of meeting the demand by existing methods was twofold: first, to generate the necessary high potential; and next, to build a discharge tube capable of standing it. The first part of the problem might possibly be solved by conventional engineering methods, but the expense would be enormous. An attempt to solve it by returning to Franklin and his lightning discharge has been abandoned, but another attempt, based on hardly less antiquated principles, seems likely to succeed. A long silk endless belt is driven at its lower end by a pulley on a small motor; at its upper end it passes over an idle pulley in the interior of a large metal sphere. The belt is charged at the lower end by the brush discharge from a pointed conductor, the charge so acquired being carried to the large sphere. A limit to its potential is reached only when conduction along the belt balances the mechanical conveyance of the charge. Even if the first part of the problem is solved, however, the second, which has not been seriously attacked, remains and may prove even more formidable. However, the amazing achievement of Cockcroft and Walton, who, relying on the power of modern pumps, built a discharge tube for 500 kV with plasticine as the sealing material, suggests such revolutions in vacuum technique that the difficulties may not in reality be as great as they seem at present. Meanwhile Lawrence has been devising methods of obtaining fast particles without using high potentials. The principle involved is simple. Two boxes, A and B, are arranged so that particles can be sent from one to the other, and an alternating potential V is applied between them. When A is positive to B, the particles (supposed to carry a positive charge) are sent from A to B, and acquire energy eV; they are kept within B while the potential changes sign, and are then sent back from B to A; their energy is thereby increased to $2eV$; and so on. The only problem is to make the particles pass between A and B in synchronism with the alternations. Two methods of solving it were adopted. In one a series of boxes A_1, B_1, A_2, B_2, . . . were arranged in a straight line, the A's being joined electrically and likewise the B's; the length of the boxes, increasing along the series as the speed of the particles increases, is adjusted so that the time taken in passing through a box is the time between potential peaks of opposite sign. Limitations on the length of the boxes confine this method to particles of large mass and low speed for a given energy; but a current of 0·1 micro-ampere carried by singly-charged mercury ions of 1 260 000 electron-volts energy has been obtained. An increase of energy to 10 000 000 electron-volts is predicted. In the other and more ingenious method the particles are made to circulate about the lines of force of a magnetic field. If the mass and charge of the particles are constant, the radius of their path increases as their velocity, and the period of circulation is independent of it. If the boxes are semi-circular in the plane perpendicular to the magnetic field, some of the particles will start across the gap at such a distance from the centre that their period of circulation is equal to that of the alternating potential difference. They will then traverse a spiral outwards with constant period but increasing velocity, until they are taken out near the circumference. A theoretical limit to this method is set by the "relativity" increase of mass with velocity, which finally leads to imperfect synchronism. A current of 0·001 micro-ampere carried by protons with an energy of 1 220 000 electron-volts has been obtained, using a potential difference between the boxes of only 4 000 volts, and further increases are contemplated. The merit and interest of this work is not diminished by the discovery that its importance for nuclear research may not be as great as was anticipated. This point will be further dealt with later.

Thermionic Amplifiers.

The study of ionizing particles and other sources of very small currents has been greatly changed by new forms and new uses of thermionic amplifiers. A lower limit to currents which can be amplified is set by the grid current of the amplifier; a study of the causes of this current has led to the production of "electrometer valves," in which it is reduced to less than 10^{-15} ampere. By means of such valves currents of 10^{-18} ampere can (ideally, at least) be measured on a galvanometer; in practice a rather higher limit is set by imperfect screening from high-frequency disturbances, but it is predicted by some that all types of electrostatic electrometer will become obsolete. Similarly the study of "valve noise" is leading to valves in which the lower limit of a.c. currents that can be amplified is greatly reduced. In the detection of individual particles, the tedious observation of scintillations, requiring great personal skill, has been abandoned in favour of the use

* A review of progress.

of improved Geiger counters or of simple ionization chambers attached to amplifiers that enable the charge liberated by a single particle to be detected. Counting is done automatically; the limitation of speed imposed by the inertia of mechanical instruments, such as those used in telephony, has been removed by the ingenious devices of Wynn-Williams, which may have a wider application. The latest depends upon the properties of the thyratron, or gas-filled relay, in which a small disturbance in the grid circuit acts as a trigger, starting anode current that may amount to many amperes, but exerting no subsequent control on it. This device is already finding wide fields for use in many departments of electrical engineering. The counter employs a principle already applied in the thyratron inverter for converting direct current to alternating current. A pair of thyratrons can be connected so that a discharge is always passing in one but not in the other; the arrival of a grid disturbance changes it from one to the other. By putting such pairs in series, an arrangement is obtained whereby each of the 2^n possible distributions of the discharges between the $2n$ thyratrons is an indication that a definite number of disturbances have arrived since the beginning of a cycle, which is repeated indefinitely. Again, in the study of cosmic rays and of some radio-activity problems the detection of "coincidences," i.e. the simultaneous occurrence of ionization in two or more chambers, is very important. Here a valve with several grids (which might be replaced by the grids of several valves in series) is employed, each grid being negatively biased and attached to a separate chamber. Current cannot pass unless a disturbance, overcoming the bias, arrives simultaneously at all of them; coincidences alone are therefore indicated.

Photo-electric Cells.

There have been notable advances in photo-electric cells. The oldest type, the selenium cell, has not changed much. It remains, in a sense, the most sensitive of all, and although its irregularity limits its use to the simplest problems, the present tendency to replace it everywhere is not always justified. The Hallwachs cell, to which the term photo-electric is generally confined, has changed much more. In 1924, Ives showed that when "inactive" metals, such as copper or platinum, giving no photo-electric emission in the visible spectrum, are coated with an invisibly thin film of an "active" metal, such as potassium or cæsium, they acquire an emission quite different from that of the active metal in bulk. The character of this emission depends on the nature of the underlying inactive metal and on the thickness as well as on the nature of the thin film, but generally the threshold of the thin film is further towards the red than that of the bulk metal. More recently this conclusion has been extended to underlying materials other than clean metals: it appears to be true whatever the nature of the support on which the thin film is deposited. This discovery opens up a wide field of possible new cathodes. In place of the simple bulk metals (which now appear as thin films on supports of the same material) we have all the possible combinations of film metal and support material, among which to seek for the best cathode for any particular purpose. The field has not been explored very thoroughly, for two reasons. One is that the demand for cathodes of different kinds is very limited. For most purposes the best cathode is that which gives the greatest emission to the light from incandescent sources. Once this has been discovered, practical interest flags. The other reason is that the emission is so greatly affected by minute differences in the supporting surface and the thickness of the film that the differences between intentionally dissimilar cathodes are apt to be obscured by those between cathodes intended to be identical. It appears certain, however, that the most practically useful cathode is that produced by heating a superficially oxidized silver surface in cæsium vapour, resulting in the deposition of a monatomic layer of cæsium on a complex of cæsium, oxygen, and silver, the exact nature of which is unknown. This cathode may have an emission to white light of at least 50 μA per lumen, 50 times as great as that of the "sensitized potassium" which was the most sensitive cathode known 5 years ago. The gain is due to the increased utilization of the red and infra-red part of the spectrum. The potassium cathode has its maximum emission near 400 mμ, the Cs-Ag-O cathode near 800 mμ. Compared at their respective maxima the former is actually more sensitive than the latter, and the emission of neither of them exceeds 3 per cent of what is theoretically possible. Still further advances in sensitivity are therefore conceivable, but there is at present no evidence of the direction in which they are to be sought.

Meanwhile a photo-electric cell of a new type has appeared. Grondhal and Geiger found in 1926 that a dry-plate rectifier of the type developed by the Westinghouse Co. could be made to give a current in the absence of any external e.m.f. by throwing light upon it. This phenomenon is now known to depend on a general property of junctions between metals and semi-conductors, a group of bodies of which cuprous oxide and selenium are notable examples. If the junction is made by pressing the two bodies into contact, the passage of electrons across it is similar in both directions; but if it is made by certain other processes, such as oxidizing a copper surface to provide the cuprous oxide and subjecting the oxidized body to an appropriate heat treatment, dissymmetry appears. Under the action of an e.m.f. electrons pass more readily from the metal to the semi-conductor than in the reverse direction, but under the action of light and in the absence of an e.m.f. electrons pass more readily from the semi-conductor to the metal. A layer of semi-conductor between two metal electrodes, with one of which it forms a symmetrical junction and with the other an asymmetrical, constitutes a rectifier passing current more readily in one direction than in the other. If the asymmetrical junction is illuminated, a photo-electric current will flow round the external circuit. Cells of this new type are essentially identical in construction with dry-plate rectifiers, and may therefore be called "rectifier cells." (The German term is *Sperrschicht*. Various translations have been suggested, but none have yet been adopted generally.) In order that the light may reach the junction, special constructions have to be adopted. In the older cells the symmetrical junction was formed by

a gauze electrode, and the light reached the asymmetrical junction through the pores of the gauze and the thickness of the semi-conductor. In the newer cells, the asymmetrical junction is formed by depositing a very thin, partially transparent, layer of metal on the semi-conductor; light enters through this layer. Both cuprous oxide and selenium are used as semi-conductors.

Under the action of white light, the best rectifier cells can give currents 3 or 4 times as large as the best vacuum cells described above; they require no battery, and are cheap and robust. They have, however, the disadvantage that the internal conductivity of the cell, regarded as a rectifier, provides a shunt across the external circuit amounting to (at most) some 10 000 ohms. They can only be used satisfactorily with comparatively low-resistance measuring instruments. The current which they give cannot easily be amplified by valves. For most of the present applications of photo-electric cells they are inferior to the older types, but they have a field of their own (namely measurements in which convenience is of more importance than accuracy) in which they are unrivalled.

The use of photo-electric cells for industrial and scientific purposes has increased greatly, owing partly to these advances in their construction, but much more to a growing appreciation of potentialities inherent in even the older types. They are widely used in substitution for mechanical indicators when, owing to the lightness or inaccessibility, for example, of the object, it is more convenient to interrupt a beam of light than to move an arm or wire. They are used also to increase speed and to remove subjective errors in the measurement of optical qualities, such as transparency. In monochromatic photometry photo-electric methods have completely replaced visual, when either accuracy or speed is required. A great step towards their use in heterochromatic photometry and colorimetry has been made by international agreement on the "visibility curve" for a normal eye, and on the primaries and standards to be used in the trichromatic specification of colour. In this field visual methods are still more accurate than photo-electric, however, and more rapid also unless very elaborate and expensive apparatus is used; but developments of Hardy's automatic spectrophotometer may possibly reverse the situation soon.

Electron Microscope.

The electron microscope is receiving attention in several quarters. It depends, not on the wave properties of the electron, but on the fact that the deflection suffered by a stream of electrons in passing through the field produced by various magnets or arrangements of charged bodies is identical with the deflection suffered by a beam of light in passing through a lens or prism. Therefore, to every optical system whereby light is focused there is a corresponding system of electrostatic or magnetic fields whereby electrons may be focused and made to produce on a photographic plate an image of their source. It is thus possible, for example, to make inequalities in a thermionic cathode give pictures of themselves; but a more fruitful application of the idea, when it is developed, may be to structures too minute to be resolved by light—for the equivalent wavelength of the electron beam may be reduced indefinitely by increasing its speed.

Chronometry.

It is now probable that, by using combinations of Shortt free-pendulum clocks with piezo-electric crystals in constant enclosures, a time-keeper can be produced more accurate than the rotating earth and capable of checking its irregularities, long suspected by astronomers but never definitely proved.

Fundamental Constants.

Measurements of the fundamental universal constants have finally resolved the discrepancy between the spectroscopic and deflection values of e/m in favour of the former, and (rather surprisingly) these measurements support crystal as against grating X-ray wavelengths.

Theory.

There has been no sudden alteration in quantum theory during the period under review, but a gradual development of great interest to the engineer has taken place. He is probably reconciled by now to abandoning the familiar models of classical theory; but he probably feels that its substitutes will not fulfil adequately their declared object of rendering phenomena predictable, so long as the only argument they admit is purely analytical, accessible only to trained mathematicians, and so long as no room is found for intuitive reasoning of the kind that the old models rendered possible. It is gratifying, therefore, to note that such intuitive reasoning is returning; perhaps the best example of it is a paper in which Gurney applies quantum theory beautifully to the phenomena at an electrolytic cathode without using any but the simplest mathematics. This has become possible because some of the most general propositions, characteristic of the most abstruse forms of the theory, can now be expressed in a way which enables them to be visualized, although they are inconsistent with Newtonian dynamics. Three examples of such propositions may be given.

(1) The electrons or other elementary particles constituting any connected system whatever can exist only in a finite number of states (within any given energy range), and each of these states can hold only a finite number of particles.

(2) A charged particle has a finite chance of passing through a potential barrier which it has insufficient energy to surmount. (This is sometimes described as the tunnel effect.)

(3) A possibility of a mutual interchange of electrons between similar systems gives rise to an "exchange energy" binding them, which cannot be represented by directed forces.

For the experimentally-minded the problem is to explain everything in terms of such propositions as these, whereas for the mathematically-minded the problem is to deduce all such propositions from simple and self-consistent principles. In this connection a great advance was made in Dirac's book* (1930) which deduced them from new axioms that, like all good mathematical axioms, emerge inevitably from the

* P. A. M. Dirac: "The Principles of Quantum Mechanics."

symbolism by which they are expressed. Gaps remain to be filled, however. General analytical methods are needed to replace the cumbrous devices that have now to be developed for each particular application, and vestigial relics of classical theory (such as the use of the Hamiltonian as a starting point) have to be removed. Moreover, there appear still to be some deep-seated inconsistencies with experiment. Some of these arise from the assumption, as inevitable as it is incredible, that the fundamental particles are mathematical points. Others arise from the attempts, still imperfectly successful, to unite quantum and relativity theory. Of these latter an example is the predicted occurrence of particles with negative kinetic energy. Dirac's delightfully humorous attempt to lay the ghost he had raised by regarding matter as a series of holes in a universe of negative energy has unfortunately proved abortive. The possibility that the error lies on the relativity rather than on the quantum side cannot be excluded. It is relevant, therefore, to remark that doubt has been thrown on the validity of one of the great experimental proofs of the theory of relativity, namely the " Einstein deflection " of light observed during a solar eclipse. It is unlikely, however, that the essential features of relativity will be abandoned on such evidence. Again, the latest discussion of the fundamental constants (e, m, M, h) does not lend much support to Sir Arthur Eddington's brilliant but rather incomprehensible attempts to combine the two great branches of theory, and thus to relate the mass of the proton to the mass and radius of the universe.

Considerable success has been attained in applying quantum theory to chemical combination, to magnetism, and to collisions between particles either charged or uncharged. In the first two fields the success is still mainly qualitative and consists in showing that relations already established experimentally are consistent with the fundamental principles of the theory. Excellent quantitative agreement is obtained in connection with collisions, and at least one new result, unexpected on the classical theory, has been confirmed experimentally; namely that certain abnormalities occur when the colliding particles are of the same kind. The main interest in all this work lies in the methods by which the conclusions are reached. No summary of it would be adequate unless much of the analysis were reproduced. However, there are two fields where theory has been equally active, which are more suitable for exposition here. These are the fields of electronic conduction and of radioactivity.

Conductors and Insulators.

Electron Theory of Conduction.

When Sommerfeld in 1928 introduced " Fermi-Dirac statistics " into the electronic theory of conduction, he removed the difficulty concerning the specific heat that had prevented progress for 20 years. He himself remarked, however, that another difficulty had appeared in its place; the free path of the electrons had turned out to be much longer and much more dependent on temperature than any reasonable theory of collisions would suggest. Indeed the new difficulty was merely a fresh aspect of the old, because the whole conception of individual free paths terminated by independent collisions was inconsistent with the new statistics. If there are values of the energy denied to one electron because they are already occupied by another in the same piece of metal, there must be a much closer correlation between the motions of different electrons than is consistent with independent collisions at the ends of unhampered free paths. In truth, Fermi-Dirac statistics are physically intelligible only if the wave, and not the particle, aspect of electrons is regarded, so that every electron is diffused through the entire metal. The question now is: What in this aspect is to replace the free path?

This question was answered in the same year by Bloch, who discussed the passage of electron waves through a crystal lattice. He found that, so long as the lattice was quite perfect, the waves passed without distortion or scattering, as might be expected. The corresponding particles would be in motion in all directions, interchanging their places in the lattice. In such a lattice a current could be made to flow without energy, and thus a metal, or indeed any substance, characterized by a truly perfect lattice would possess infinite conductivity and the calculated free path of the electrons would be infinite. If, however, there were any imperfections and any departures from periodicity in the lattice, then a current could be maintained only by an expenditure of energy. There would be no truly free electrons, and the free path, calculated on the assumption that there were, would be finite. The metal would possess a resistance which would increase with the departure from periodicity. Imperfections of the crystal lattice (which may lead in the end to the almost random distribution of a liquid) are, according to Bloch, the source of all metallic resistance, whether they arise from the irregular thermal motion of the ions, from the admixture of foreign atoms, or from the action of a magnetic field.

This theory accounts for everything explained by the older theory, such as the various thermo-electric relations and the Wiedemann-Franz law. At the same time it gives approximately correct absolute values for the resistance in terms of measurable properties alone; and, without any of the *ad hoc* assumptions about the free path previously necessary, it explains the general variation of resistance with temperature, Matthiessen's rule for alloys, and the high resistance of solid solutions —in fact everything that, according to the older theories, was known to depend on the free path. On the other hand it leaves untouched the difficulty about the effect of strong magnetic fields on resistance, and our ignorance of superconductivity. However, the removal of an unknown factor, in which the solutions of these problems might have been found, does not necessarily deepen the mystery. There are still loopholes for explanation in the shape of such neglected factors as the mutual influence of electrons. Indeed, Bloch's theory makes superconductivity slightly more intelligible. For it is clear that in an imperfect lattice (such as every crystal above absolute zero of temperature must be) it can arise only from delicately adjusted quantitative relations in very complicated systems; it must be of the nature of an accident. This is also the impression conveyed by the results of the latest experiments, which show that alloys,

especially those containing metals which are super-conducting in the pure state, may be super-conducting at temperatures higher than any of their constituents, and, more generally, that the factors determining super-conductivity are extremely complex.

The older theories attributed the distinction between (metallic) conductors and insulators to the presence and absence respectively of free electrons. A distinction on this ground can be maintained no longer. In a perfect lattice all electrons, however tightly they may be bound to ions, are free, whereas in an imperfect lattice none are. At the same time a place has to be found for a third class of bodies, only lately defined clearly, namely (electronic) semi-conductors. These bodies, of which Cu_2O is typical, are insulators when perfectly pure; but traces of impurity (probably O in the case of Cu_2O) produce a very considerable conductivity, which increases rapidly with temperature and yet is not of electrolytic origin. According to the new theory, the difference between the three classes arises from the distribution of the possible energy-states of an electron in a lattice. This distribution is not continuous, but consists of bands within which all values of the energy are possible, separated by forbidden zones in which no value of the energy is possible. The presence of these bands is manifested in Davisson and Germer's experiments on electron reflection. For, roughly speaking, the electrons totally reflected are those which, if they penetrated within the crystal, would have energies lying within a forbidden zone. The number of states in a band, like the number of electrons, is an integral multiple of the number of atoms in the metal. It is therefore possible that, at low temperatures, when only the states of lowest energy are occupied, the number of electrons may be just sufficient to fill up some of the lowest bands, leaving none over for the next highest band separated by a gap. In this case the body will be an insulator, unless the lattice is quite perfect, for a current can be produced only by communicating energy to the electrons. Since, however, all the energy-states immediately above those actually occupied are forbidden, an electron cannot take up energy unless it is given enough to carry it across the gap, which will represent a potential difference of at least 1 volt. Such an amount of energy it could receive only from the very large field that might "break down" the insulator. On the other hand, the ratio of number of electrons to number of states may be such that some fraction (say, $\frac{1}{2}$ or $\frac{1}{3}$) of the highest band is occupied, while the remainder is unoccupied. The electrons in this band can receive small amounts of energy, and the substance will therefore be a metal conducting readily under small fields. Lastly, in the semi-conductor we must suppose (and it is not unreasonable to do so) that the impurities provide occupied energy-states just below an unoccupied band of the main substance; rise of temperature will give electrons in these states sufficient energy to cross to the band, where they can receive energy from the field and convey a current. The higher the temperature, the more electrons cross to the band, and the greater the conductivity. To complete the theory it must be shown that the distribution of electrons in the atom or molecule known to be associated with metallic or non-metallic properties will lead respectively to a partially or a wholly occupied band in the solid substance, and that in known semi-conductors the energy-states of substance and impurity are related as supposed. Proof of the first part of this proposition will probably be forthcoming. Much more knowledge of chemical combination must, however, be obtained before the second part can be proved, but there is some evidence for it in the fact that semi-conductivity is a fortuitous property, not simply related to any other.

The difference between a metal and a semi-conductor in regard to the number of electrons available for conduction, and in regard to the distribution of the states that they can occupy, causes asymmetry in the passage of electrons across a contact between them. The effects of this asymmetry will vary with the gap at the contact, i.e. with the width of the potential barrier that the electrons must penetrate. A circuit in which the two gaps are unequal will rectify. A wide gap may be provided by a layer of the pure, and therefore insulating, semi-conducting material. An approximate quantitative theory of the dry-plate rectifier, based on these ideas, agrees with experiment. Thus an apparently mysterious phenomenon has been explained.

Thermionics and Photo-electricity.

On the other hand, the emergence of electrons from a metal into a vacuum (thermionics and photo-electricity) still presents some difficulties, especially when the metal surface is covered with films of foreign material. In thermionics these concern A in the Richardson equation

$$i = AT^2e^{-b/T}.$$

A is determined by the chance that an electron striking the surface with sufficient energy to overcome the potential difference at the surface will actually emerge. If this chance is 1, A should be 120 amperes per cm^2, and no greater value should be possible. Actually, however, greater values are found. It is probable that the explanation lies in a variation of b with temperature, which leads to the appearance in the experimentally-determined A of a factor that theoretically belongs to b, but it is not at all clear how such a variation can arise. In photo-electricity the problem is to predict the relation of the emission to the frequency and plane of polarization of the light, especially when the effect is "selective," and the variation of this relation with the nature of the surface layers. Very little success has been attained, and not only because the nature of these layers is still obscure. The relation must depend on (*a*) optical properties that determine the light acting on the electrons inside the metal, (*b*) the interior atomic fields that determine the chance of an electron taking energy from the light, and (*c*) the surface potential barrier that determines its chance of emerging. The part played by each of these factors is still in dispute. These difficulties hamper equally the theory of the new rectifier cells dealt with above, which is not essentially different. However, one simple case of the general problem has been completely solved. Fowler has deduced a relation between emission, frequency, and temperature, valid in the neighbourhood of the threshold, which has enabled thresholds to be determined without ambiguity and their

suspected relation to the thermionic work function to be definitely established for clean metal surfaces.

Radioactivity.

The validity of quantum principles within the nucleus had been probable since it was shown that the Ritz combination law was true for γ-ray, as well as for optical and X-ray, spectra. γ-rays must be the radiation emitted in a transition from one nuclear state to another. The abandonment of the old view that γ-radiation is a by-product of β-radiation, however, introduced some new difficulties. First, the heterogeneity of the primary β-rays was left unexplained and apparently inconsistent with quantum principles. This heterogeneity is one of the gravest problems of radioactivity. No solution of it is in sight, and meanwhile the conservation of energy in nuclear processes is doubtful. Secondly, it became difficult to explain the surprisingly large " internal conversion coefficient," or probability that a γ-ray will eject an electron from the atom in which it arises, producing a secondary β-ray. This difficulty has been partially reduced; the facts have been shown to be consistent with a distribution of nuclear states which is probable on other grounds. Thirdly, there was some doubt as to what are the states concerned in the transition which gives rise to the emission of γ-rays in an α-ray disintegration. Evidence concerning the nature of these states has now been obtained, and at the same time an outstanding puzzle has been solved. It has long been known that a minute fraction of the α-rays from RaC (and some other atoms) are much faster than the homogeneous remainder. Lord Rutherford and his colleagues have now proved that the difference in energy between an abnormally fast α-ray and a normal α-ray is equal to the energy of a γ-ray from the same source. The conclusion is inevitable that the emission of a β-ray that produces RaC from RaB, leaves the nucleus in an " excited " state. From this state it can proceed to the " unexcited " state by one of two (or more) alternative transitions; either it can emit first a γ-ray and later a normal α-ray or it can emit a single abnormal α-ray. The probability of the former (two-stage) transition is much greater than that of the latter (single-stage) transition.

The association of γ-rays with α-rays, suspected before it was thus proved, led to a search for artificial γ-radiation excited by the α-ray bombardment of light atoms. Bothe and Becker in 1930 proved definitely that such radiation was emitted from Li, B, Be, F, and Al. It must be insisted that the subsequent work, about to be described, throws no doubt on their conclusion; part of the radiation they detected is certainly γ-rays. However, when the Curie-Joliots studied more intensively the radiation from bombarded Be (which had been found to be peculiarly intense and penetrating), they discovered properties that distinguished it from any known form of radiation. Unlike β- and γ-radiation, it reacts with the nuclei rather than with the electrons of the atoms it strikes. Thus it ejects fast protons (i.e. hydrogen nuclei) from any substance containing hydrogen, and its absorption is determined by the number of nuclei rather than by the number of electrons encountered. On the other hand, its penetrating power is incomparably greater than that of any known α- or proton-rays (which react with nuclei). The latter are all stopped by 1 mm of Al, whereas the new rays penetrate 50 cm of Pb.

The problem was solved by Chadwick's suggestion, confirmed by all subsequent experiments, that this novel radiation consisted of particles of atomic mass carrying no electric charge. Their mass would make them react with nuclei rather than with electrons, but in the absence of a charge the reactions that stop and scatter α-rays would be absent. The existence of such " neutrons " had often been suspected; here was experimental evidence of it. The mass of the neutron, determined from Wilson photographs of its collisions with other nuclei, turned out (as had been expected) to be very nearly that of the proton.

Neutrons have remarkable properties, interesting to the lay mind. Thus a collection of them would form a gas which, since it would pass through any wall, would be detected by neither manometer nor balance. Their chief function in serious theory, however, is to remove certain difficulties in connection with the structure of atomic nuclei. Thus the band spectrum of nitrogen, interpreted in accordance with the " exchange principle " of quantum mechanics, indicates that N^{14} contains an even number of elementary constituents. If it is built of protons and electrons it must contain an odd number, viz. 14 protons and 7 electrons, but it might be built of 7 protons and 7 neutrons. (Here it may be recorded that the study of band spectra, which represent the vibrations of nuclei, is throwing much light on their mass and constitution. It has led to the discovery of many isotopes present in small proportions, e.g. O^{17} and O^{18}, and thus to unfortunate—but not yet serious —difficulties in the scale of the atomic masses, hitherto based on the assumption that O^{16} was the only isotope.) The existence of neutrons raises at least as many problems as it solves; for the fundamental assumptions of modern theory make it impossible either to explain how a neutron can be composed of a proton and an electron, or to admit that it is not so composed. The trouble doubtless lies again in the assumption (already dealt with) that protons and electrons are points; but if they are not, what determines their dimensions? A crisis in nuclear physics seems to be approaching comparable with that in extra-nuclear physics which led to Bohr's theory nearly 20 years ago.

The principle of the " tunnel effect " has also played its part in radioactivity, since Gamow, and simultaneously Gurney and Condon, suggested that the characteristically fortuitous disintegration was determined by the finite probability that an α-particle, possessed of energy within the nucleus, will penetrate at any moment the high-potential barrier at the boundary. This theory explained the known Geiger-Nuttall relation between life and energy of final disintegration, and predicted previously unknown relations, since at least partially established, such as that α-particles of a particular speed should penetrate the nucleus more readily than those of either higher or lower speed. It did not, however, prepare us, as it should have done, for the great surprise when Cockcroft and Walton succeeded in disintegrating even the heavier atomic nuclei with protons of an energy corresponding

to less than 500 000 volts. It is still a complete mystery how particles with so little energy can penetrate the nucleus, but it will doubtless be solved shortly and will then throw a flood of light on nuclear structure. Meanwhile the bare facts are very interesting: the most striking case is possibly that in which Li^7 takes up a proton of about 150 kV energy and is transformed into two α-particles (He^4), each of some 8 000 kV energy. Unfortunately, only 1 proton in about 10^9 achieves these results, so that the novelist's dream of unlimited supplies of available atomic energy remains unfulfilled.

Miscellanea.

Electric Discharge Through Gases.

The theory of the electric discharge through gases, especially at low pressures, which has long been a matter of the greatest interest, is now becoming a matter of practical importance. Discharge lamps, which have occupied a field of their own in display and advertising, are about to invade the field of incandescent lamps. Their permanent merit is their high efficiency, their present demerit the colour of the light. The efficiency of conversion of electrical energy into energy of visible radiation within the lamp itself (as distinct from subsidiary devices for control) may now attain to as high a figure as 15 per cent, and is actually higher than was predicted as ideally possible on the basis of the incomplete theories of 10 years ago. The theory is, however, still far from complete. An immense advance was made when Langmuir and Compton distinguished the "plasma" from the "sheaths." The "plasma" is a region of low electric fields in which positive and negative ions (or electrons) are present in equal concentration, their velocities being determined by a temperature (different for positives and negatives, and generally much greater than that of the discharge tube) with its appropriate Maxwell distribution. The "sheaths" are regions, usually in the neighbourhood of electrodes and walls, where the ions are exposed to forces due to "space charges," related both as cause and as effect to their unequal distribution. They are also the regions where the main production and disappearance of ions occur. When any form of discharge has been analysed into a distribution of plasma and sheaths with these general properties, the distribution of current and potential throughout it can be predicted, qualitatively if not quantitatively. In a certain sense, therefore, the discharge has been explained. Explanation of all the chief types of discharges up to this point was achieved some years ago, but progress in certain details was still possible. Thus, the difficulty of understanding how the ordered motion of the ions in the sheaths became transformed so quickly into the completely disordered motion of the plasma has been solved recently by the proof that the plasma is capable of very rapid small-scale vibrations under the mutual attraction of its particles. Again, the study of discharges in vessels without walls (the anode being a sphere surrounding a small central cathode) has enabled some of the laws of the plasma to be established more firmly. In particular, it appears that the plasma in a rare gas is actually, as it should be, a practically perfect conductor.

However, even if all such matters were completely understood, the problem would still remain of accounting for the distributions of plasma and sheaths that are actually found to occur, and for the potential differences observed in the latter. Here much is still uncertain; indeed it is doubtful whether, even in the simplest type of discharge, the relation between potential and current (mainly determined by the sheaths) can be predicted accurately from first principles and a knowledge of the atomic properties of the substances concerned. Much has still to be discovered about the production of ions, both in the gas and at the electrodes. Thus the bare facts concerning ionization by the passage of positive ions are still not beyond dispute. Again, the conception of positive ions causing the emission of electrons from the cathode "by impact" has become meaningless. The emission varies with the speed of the incident positive ions because it is the resultant of many diverse processes which have to be studied individually. Of these, one that has received much attention is photo-electric emission under the resonance radiation of the gas that is transmitted by a process resembling diffusion, and another is a reaction with excited metastable atoms that also diffuse. Both these processes are affected profoundly by small traces of impurity, atoms of which react with the resonance radiation and with the metastable state quite differently from the atoms of which these are characteristic. In all these matters progress is steady and continuous, but a final solution of problems that require the quantitative analysis of a mixture of many complicated processes cannot be expected immediately.

Penetrating Rays.

The penetrating rays, sometimes known lately as cosmic rays or *Hohenstrahlung*, continue to excite interest. The rays immediately detected in ionization chambers, and now in Wilson photographs, are certainly corpuscular and at least partly secondary in origin. The intensity of the rays increases regularly, but at a decreasing rate, with decrease in the mass of the overlying atmosphere. The diurnal variation with the sun's altitude, which was suspected at one time, is definitely spurious, but it is not certain that there is not a small true diurnal variation. The variation with position on the earth's surface does not greatly exceed 30 per cent of the mean, but an increase at the higher magnetic latitudes is suspected. Part of the ionization produced by the rays occurs in bursts of unusual intensity, such as might result from nuclear disintegration. The interpretation of the facts is obscure. Heisenberg suggests that no theory, consistent with prevailing conceptions, can account for all of them, though explanations for some of them are easy enough. It is still uncertain whether the primary radiation is corpuscular or quantum; and whether the corpuscular radiation, which may be only secondary, is electronic, protonic, neutronic, or all three. The possibility of a terrestrial source, once almost abandoned, is now being reconsidered. It is at least certain that the far-reaching speculations on cosmology and the origin of matter, to which one phase of the study of these rays gave rise, are quite unfounded.

THE RECOVERY OF DEEP-SEA CABLE.*

By J. C. Besly, Member, and H. V. Higgitt.

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Summary.

The kinking of deep-sea cable during repairs, and the failure of the cable to coil properly when an endeavour is made to recover it, are troubles which are as old as the art. The paper attributes these troubles to two causes—the tendency of laid-up cable to unlay under tension, and the twisting action of the bow sheave when the cable trends outboard to port or starboard. An example is given of a method of calculating the tendency to unlay under tension. It is shown what are the effects resulting from a trend of the cable to port, to starboard, and when central; also that the variation of the effects when the trend is altered follows an exponential law. It is further shown that a certain trend of the cable outboard enables torsion in the suspended cable to be avoided during pauses in picking up, thus avoiding kinking at the bottom, and that the constancy of the trend conduces to satisfactory coiling. Novel forms of sheaves are described which would facilitate keeping the cable outboard at a constant trend relative to the sheave.

Historical.

In 1883 a paper was read before the Institution by Messrs. S. Trott and F. A. Hamilton, entitled "Submarine Telegraph Cables: Their Decay and Renewal,"† in which the statement was made that "An iron-armoured cable cannot be recovered from deep water excepting in short lengths, because the operation of heaving-in causes the armour to unlay or untwist, and this results in an accumulation of turns at and near the ocean bed, and a wringing or wrenching asunder of the fabric is sure to occur." In this early paper it was proposed to avoid such troublesome effects by using no metal sheathing at all, and laying on instead two layers of hemp, one with right-hand lay and the other with left-hand lay. Thus torsional effects were experienced even in the earliest days of submarine cable engineering, and were recognized by Messrs. Trott and Hamilton as due to the tendency of a laid-up cable to unlay under tension. In view of this early recognition of the cause of torsion, which undoubtedly and frequently led to the kinking of cable, it seems remarkable that until comparatively recent years apparently no endeavour was made to investigate the subject logically and scientifically. While it is unsafe to say that no work has been done on the subject, such work as may have been done has had no permanent effect on the art of submarine cable engineering so far as the recovery of cable is concerned. Had Messrs. Trott and Hamilton confined their paper to the torsional effects observed when picking up cable, it might have led to investigations culminating in some substantial advance in deep-sea cable-work procedure. They further stated, however, that the effects also occurred when laying cable, and this, together with their proposal of a hemp-closed cable, laid them open to severe criticism, not least from the then President, Mr. Willoughby Smith, who stated that the company with which he was connected had laid 94 000 miles of cable without experiencing the effects to which reference had been made. Up to that time few or no efforts had been made to recover substantial lengths of submarine cable, but the effects due to torsion had clearly resulted in serious troubles during the course of cable repairs, and such troubles are still encountered.

"Screwing" and Kinking of Cable.

The principal effects which will be dealt with in the present paper are two in number—"screwing" and kinking. By "screwing" is meant the refusal of the cable to coil in a normal manner; this effect is frequently evidenced by the cable coiling itself in the tank in a series of small turns (2 to 3 ft. in diameter). A kink, of course, results from the pulling-out of a turn. Until comparatively recently the occurrence of these two effects, when picking up deep-sea cable, was considered to be so inevitable that a large proportion of the value of the cable (so far as it could be regarded as a movable asset) was considered to be lost immediately it was paid overboard, since the effects made it impracticable to recover more than a very small fraction of the cable in a fit condition to re-lay. Screwing and kinking are of frequent and even usual occurrence when picking up cable in deep water. Fig. 1, which provides evidence of the crippling of cable due to the effects of torsion, illustrates a typical form of trouble experienced during cable repairs when hanging on to an end in deep water for the hour or two necessary to join and splice it to the cable inboard. This case was met with during a repair to the Durban–Mauritius cable in 1928, in a depth of from 2 000 to 2 500 fathoms. The sheathing consisted of 17 No. 14 B.W.G. wires, each wire being taped. About 15 kinks were formed in a length of 2 ft. Since a kink is caused by the pulling-out of a turn, it is evident that these kinks must have been formed one at a time. There is little doubt that each turn was thrown on to the bottom as the bow of the ship fell in the swell, the throwing of the turn being assisted by the torsion in the cable, which caused the turn to pull into a kink as the bow of the ship rose. The first evidence of trouble in a case like this is the sudden loss of insulation due to the copper being forced through the gutta percha by the kinks. When the cable parts, it does so as a result of the tension on the kinks as they approach the surface when the cable is picked up in an endeavour to locate

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† *Journal I.E.E.*, 1883, vol. 12, p. 495.

the fault. In view of the amount of cable recovered in picking-up to the kinks, there is no doubt that these are formed at, or very near, the bottom. It was such cases as this that Mr. Trott had in mind when he stated in 1883, during the discussion on his paper,* that " The breakages I refer to always occur on the bottom, where there is little or no strain (i.e. tension) on the cable."

The torsion in the suspended cable will sometimes cause the cable on the bottom to lay back on itself for several fathoms and twist up into twin cable. In one instance a tangle of such twin cable came aboard when picking up a section of the Cienfuegos–Santiago cable in 1920 in a depth of 2 400 fathoms. What will seem very extraordinary to seamen is that this tangle came in with the cable beyond unbroken; thus the weight of nearly $2\frac{1}{2}$ miles of cable must have been pulling on the tangle. It is quite certain that this tangle had not already existed on the sea bed, but had resulted from the operation of picking up. The cable was sheathed with 16 No. 14 wires, each wire being taped, and had been down for 16 years. The report on this repair is full of references to kinks and of such remarks as " cable would not coil in the tank, springing up into tight turns and twists."

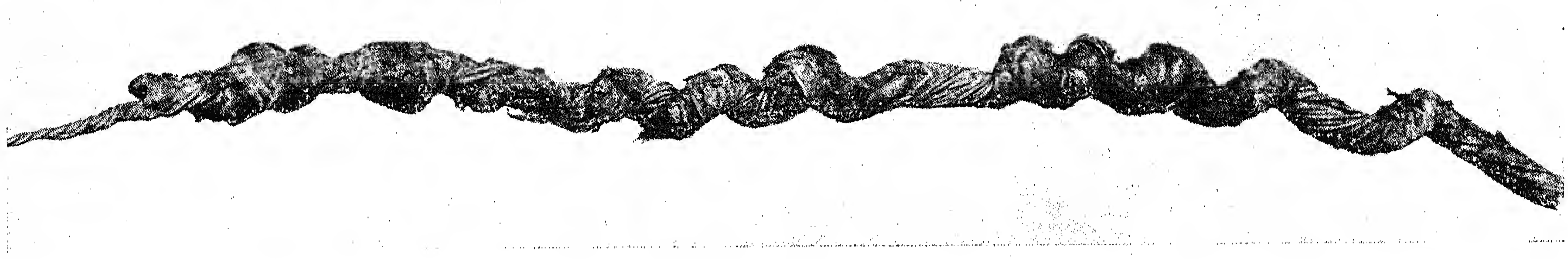

Fig. 1.

Causes of Torsion.

Leaving now the evidence of the effects of torsion, let us consider its causes. There appear to be two important causes to be considered:—

(*a*) the tendency to unlay under tension, which is common to any laid-up rope or cable;

(*b*) the action of the usual V-shape bow sheave, which lays up or unlays the cable as it comes inboard, according as the cable trends to starboard or to port respectively (left-hand-lay cable being considered).

(*a*) *Tendency to Unlay Under Tension.*—The tendency of a laid-up rope to unlay under tension is a matter of common experience, e.g. the spinning of the end of a crane rope when it comes under stress (provided, of course, that the rope is not of the "non-rotating" type, composed of layers of opposite lay). The tendency to unlay is clearly due to the endeavour of the wires to pull straight; resisting this tendency there is the torsional strength of the wires, since if they are to pull straight the wires and the rope as a whole must twist. No doubt calculations have been made of the extent to which a rope will unlay under tension, and perhaps formulæ have been arrived at, but in the absence of knowledge of any such work the following method was used. It is best made clear by applying it to a specific type of cable. The following data are those of a specimen sheathed with 15 No. 13 wires of homogeneous iron which had been recovered from the Alexandria–Larnaca cable. The torsional elasticity of each of the wires was measured separately, the measurement being that of the torque necessary to produce a twist of 90° in a length of 33 in. As this amount of twist was less than half that required to effect any permanent set in the wire, the latter was always well within the torsional elastic limit. The torsional elasticity of the 15 wires varied from a minimum of 1·38 inch-pounds (i.e. 1·38 lb. acting tangentially at a distance of 1 in. from the centre of the wire) per degree twist per inch length to a maximum of 1·70, with a mean of 1·52. The difference between the maximum and minimum may appear excessive, but possible differences in material and diameter are probably quite sufficient to explain this.

The second factor controlling the amount of unlay under tension is the angle of lay, which is the angle between the axis of a sheathing wire at any point and the longitudinal direction of the cable. In the specimen under consideration, the diameter over the wires was 0·575 in., the diameter of the No. 13 wires 0·095 in., and the length of lay 9·52 in. This gives an angle of lay (θ) of 9°.

For W lb. tension on the cable, there will be $W \tan\theta$ lb. acting tangentially at right angles to the axis of the cable, and at the mean radial distance of the wire from the centre of the cable (i.e. 0·240 in.). The torque will therefore be $0{\cdot}240W \tan\theta$ inch-lb. Values of this for a decreasing angle of lay are shown in the Table (column 3) for a tension of 1 lb. The length of lay corresponding to the angle of lay is shown in column 4.

The amount the cable is twisted is proportional to the variation of $\tan\theta$ so produced. If the wires were pulled out straight (i.e. $\theta = 0°$), $\tan\theta$ would be varied by 0·1584, and the wires would have been twisted through one turn (360°) in a length equal to the lay (9·52 in.), i.e. through 360°/9·52 per inch length of cable.

Thus $\qquad 360/9{\cdot}52 = \text{constant} \times 0{\cdot}1584$

Therefore the constant $= 238{\cdot}7$, and the twist per inch (in degrees) $= 238{\cdot}7(\tan 9° - \tan\theta)$.

The variation of $\tan\theta$, i.e. $(\tan 9° - \tan\theta)$, is shown in column 5, and the number of degrees per inch through which the cable must be twisted in order that θ may have the values given in column 1 is shown in column 6.

The torsional elasticity of the cable under consideration is very closely equal to 1·522 multiplied by the number of wires (15), and reduced by 1 per cent for the extra

* *Loc. cit.*

length of wire due to the lay, the result being the torque per degree twist per inch length. Therefore

Torque per degree twist

$$= 1 \cdot 522 \times 15 \times \frac{99}{100} \text{ in.-lb. per inch}$$
$$= 22 \cdot 6 \text{ in.-lb. per inch.}$$

The torque required to twist the cable to the degree shown in column 6 is tabulated in column 7; the figures in the latter were obtained by multiplying those in column 6 by 22·6. By dividing the torque (B) shown in column 7 by the value for $0 \cdot 240 \tan \theta$ ($=A$) shown in column 3, we obtain the tension on the cable necessary to obtain the appropriate torque. This is shown (in lb.) in column 8, and (in cwt.) in column 9.

The number of turns each wire makes around the cable per fathom is given in column 10, and the number of turns of untwist per fathom in column 11. A curve showing the turns of unlay (column 11) plotted against the tensions (column 9), and carried on beyond the limits of the Table would be asymptotic to the value 7·563, since this is the number of turns necessary to unlay the cable completely, a result which would theoretically be produced by infinite tension.

TABLE.

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)
θ	Tan θ	$0 \cdot 240 \tan \theta$ ($= A$)	Lay $= 1 \cdot 508/\tan \theta$	$\tan 9° - \tan \theta$	Twist per inch	Reactive torque of wires ($= B$)	Tension (in lb.) necessary to produce torque ($= B/A$)	Tension (in cwt.) necessary to produce torque	Lays per fathom	Unlay
degrees			inches		degrees	in.-lb.				turns per fathom
9·0	0·1584	0·0380	9·52	0	0	0	—	—	7·563	0
8·8	0·1548	0·0372	9·74	0·0036	0·86	19·4	522	4·66	7·392	0·171
8·6	0·1512	0·0363	9·97	0·0072	1·72	38·9	1 072	9·57	7·222	0·341
8·4	0·1477	0·0354	10·21	0·0107	2·55	57·6	1 627	14·53	7·052	0·511
8·2	0·1441	0·0346	10·47	0·0143	3·41	77·1	2 229	19·90	6·877	0·686
8·0	0·1405	0·0337	10·73	0·0179	4·27	96·5	2 864	25·57	6·710	0·853
7·8	0·1370	0·0329	11·01	0·0214	5·11	115·5	3 511	31·35	6·539	1·024
7·6	0·1334	0·0320	11·30	0·0250	5·97	134·9	4 215	37·64	6·372	1·191
7·4	0·1299	0·0312	11·61	0·0285	6·80	153·7	4 926	43·98	6·201	1·362
7·2	0·1263	0·0303	11·94	0·0321	7·66	173·1	5 713	51·00	6·030	1·533
7·0	0·1228	0·0295	12·28	0·0356	8·50	192·1	6 512	58·14	5·863	1·700

By the courtesy of the Telegraph Construction and Maintenance Co. a test was made at Greenwich in November 1928 upon a specimen of cable similar to that considered in the above calculation. Each of the ends of a few fathoms' length of the cable was passed through a thimble, laid back, and seized. The length over the thimbles was 16 ft., and the length between the seized ends, i.e. the length of single cable, was 10 ft. 2½ in. When a weight of 2 tons was lifted by means of this sample length of cable, the weight, which was allowed to turn slowly, did so to the extent of 2½ turns; this, if taken as being all in the 10 ft. 2½ in. between the seizings, amounts to approximately 1·4 turns per fathom. Since there must have been some unlay in the seized ends, the result of the test compares very closely with the value of 1·25 turns per fathom obtained by interpolation from the table. When the weight was removed the cable laid itself up again to its original condition.

(b) *Twisting Action of Bow Sheave.*—Having established that there is a very considerable tendency for the cable to unlay when subjected to the tensions normally encountered during submarine-cable operations in deep water, we will pass on to the second important cause of screwing and kinking, i.e. the action of the bow sheave in twisting the cable. This twisting action is an observable fact, and can take place to the extent of at least 1 turn per fathom. The twisting is due to the rolling of the cable into the groove of the sheave (as the latter revolves) when the cable outboard is to port or starboard of the plane of the sheave. With very few exceptions, the bow sheaves of cable ships are of **V** formation, and are fixtures in the ship—apart from their rotational movement. They are incapable of swivelling movement. The bottom of the **V** is not sharp, but has a radius of about 1 in., which is considerably greater than the radius of deep-sea cable (of the order of ½ in.). When the cable trends to port or starboard, the first point it touches as it is picked up is the side of the " radius " in the bottom of the **V**; as the cable passes round the sheave it rolls into the bottom, remaining there without further turning until it leaves the sheave inboard. With the usual left-hand-lay cable, this rolling results in the cable, when trending to starboard outboard, being laid up between the point where it first touches the sheave and the point where it reaches the bottom of the **V**. It further results in the cable outboard being revolved anti-clockwise when looking downwards, causing the cable to be unlayed if (as is usual) the end is not free to turn. When the cable trends to port the effects are reversed, the cable being unlayed on the sheave and layed up outboard.

The amount the cable is twisted by the rolling action

varies with the design of the sheave, the type of cable, and the extent of the trend to starboard or port. It is also to be expected that it would vary with the tension on the cable, but probably not to any marked extent provided the tension exceeds a certain minimum. Experiments have shown that the amount of twisting is not even approximately a straight-line function of the degree of trend to starboard or port; a very small trend is sufficient to show a substantial amount of twisting, and the increase in the twisting falls off rapidly as the trend increases. In general, the smaller the cable, the more the twisting. So far as the authors are aware, little has been done to investigate the effects of different designs of sheaves, beyond trials which showed that a sheave having a cylindrical periphery with flanges caused very little twisting. There are definite objections, however, to the use of a flat sheave when working in deep water, and further, as will be shown later in the present paper, twisting is necessary for the satisfactory recovery of deep-sea cable.

Practical Effects of Torsion.

The results of the combined action of the two causes of screwing and kinking put forward above were the subject of a theoretical investigation in 1919 by one of the authors; they can best be made clear by taking a hypothetical case such as might be met with in average deep-water experience. We will consider the cable to weigh 1 ton per naut in water, and to unlay (when free to turn) $\frac{1}{2}$ turn per fathom per ton tension. This straight-line law is not rigorously accurate, as was shown by the previous calculations, but it is sufficiently so for the purpose in view. We will suppose the depth to be 2 nauts, or approximately 2 000 fathoms. When this cable is hanging substantially perpendicularly from the ship to the sea bed, there will be a tension throughout the suspended cable which will vary from 2 tons at the surface to zero at the sea bed, provided that picking up is not taking place at the time. There will be a tendency for the suspended cable to unlay at each point to an extent closely proportional to the tension at that point. In other words, in an imaginary zero condition with the cable of normal lay throughout, there would be a maximum torsion at the surface tending to unlay the cable, dying away to no torsion at the bottom. If the bottom end were free to turn, i.e. if the length of cable were less than the depth of water, the cable would spin round until the torsion was relieved throughout. If, however, as is usual, the bottom end of the suspended cable is not free to turn, the greater torsion in the upper part of the cable will overcome the lesser torsion in the bottom part, resulting in the upper half of the suspended cable being unlayed and the lower half being laid up. Assuming that the upper end has not been allowed to turn (it might conceivably do so as the result of picking up a bight), the upper half of the cable will have a longer lay, and the lower half a shorter lay, than normal. At the surface the cable will be untwisted to the extent of $\frac{1}{2}$ turn per fathom, and near the sea bed the cable will be twisted up to the same extent. The laying-up of the lower part results from the fact that the torsion throughout the suspended cable must be uniform, since only the friction of the water to the rotational movement of the cable acts to prevent this, and such friction is clearly negligible when account is taken of the slowness at which a bight is raised. The torsion, which, in the hypothetical zero condition of normal lay throughout, is a maximum at the surface and zero at the bottom, may be considered to average itself out throughout the whole length of the suspended cable. In the case under consideration this average torsion would be in practice of the order of 60 in.-lb. (60 lb. acting tangentially at a distance of 1 in. from the centre of the cable), and, provided the cable is not buried, would result in turns being thrown at the bottom which will pull into kinks as picking-up proceeds. The conditions as above outlined are shown in Fig. 2.

The tension in the cable at the surface results in an elongation of the cable, and therefore in a lengthened

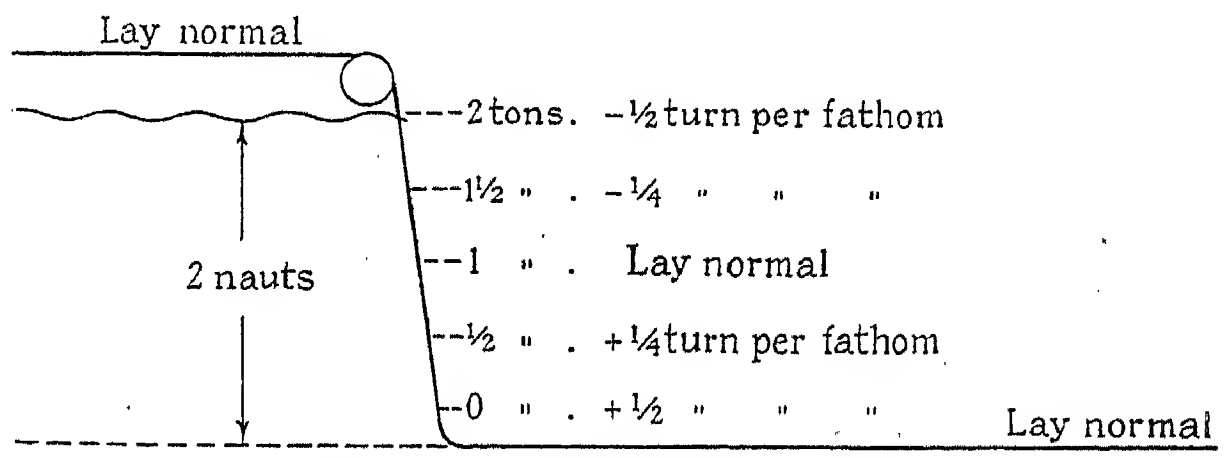

Fig. 2.—Average lay normal.

lay, but this elongation is so very small that the effect on the lay is quite negligible compared with the effects of torsion and of the twisting action of the bow sheave.

Condition of Cable During Picking-up Operations.

If picking-up be commenced and continued without any twisting action by the bow sheave, cable with a lengthened lay will be taken inboard whilst cable of normal lay will be lifted from the sea bed. The number of lays taken inboard is therefore less than the number of lays lifted clear of the bottom, so that the number of lays in the suspended cable will increase. This increase will continue until the number of lays per unit length being taken inboard is the same as the number of lays being lifted clear of the bottom; and, since the cable being lifted from the bottom is of normal lay, the final condition is that the cable taken inboard is of normal lay. Another way of appreciating this final condition is to consider that it is inconceivable for the suspended cable to continue indefinitely to accumulate twists, i.e. for it to continue indefinitely to change its lay. Therefore, when the suspended cable has reached its limiting condition, the cable taken inboard must be of normal lay, since it can only differ from the cable on the sea bed by virtue of a change in the condition of the suspended cable. Further, since there is, by hypothesis, no twisting action by the bow sheave, the cable on either side of it will be of equal lay (ignoring any twisting effect due to the deck leads), but owing to the difference in tension at the top and bottom of the suspended cable the bottom will have about one more lay or turn per fathom than the top; therefore, the top being of normal lay, the bottom will have about 1 turn per fathom above normal. These conditions are shown in Fig. 3. The change from the conditions shown in Fig. 2 to those shown in Fig 3 will

follow an exponential law, the lay being the dependent variable and the length of cable picked up the independent variable. 63·4 per cent of the change from one condition to the other will take place during the recovery of a length equal to the depth of water, then 63·4 per cent of the remainder during the next similar length, and so on.

The conditions can perhaps be visualized better by means of a curve, the abscissæ representing the length of cable from bow to bottom, and the ordinates representing twist (twist-up being positive and untwist negative). The curve showing the conditions of Fig. 2 will thus be a straight line starting at $y = -\frac{1}{2}$ and finishing at $y = +\frac{1}{2}$. Picking-up now consists of the removal of elemental areas ydx, causing the curve to move upwards until it starts at $y = 0$ and finishes at $y = +1$, corresponding to the conditions in Fig. 3. The slope of the line remains the same, since this signifies that the difference in lay between the top and bottom remains constant, which is the hypothesis. The rate of variation of the conditions is proportional to the size of the elemental areas ydx, and to this only, since cable of normal lay is being lifted off the bottom, and this process neither adds to nor subtracts from the total area. The change in area is equivalent to the change in y, which becomes

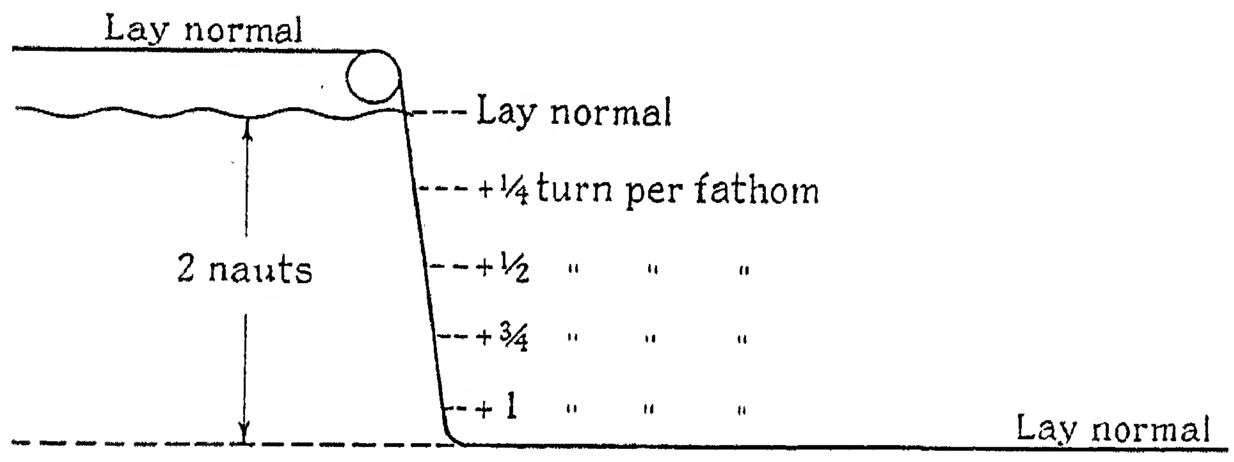

FIG. 3.—Bow sheave not twisting.

more positive; and the rate of change of area to the rate of change of ydx, that is, $-dy/dx$, since y is negative. We therefore have the well-known differential equation, $dy/dx = -y$, the solution of which is $y = e^{-x}$. This establishes the exponential law.

To solve the problem rigorously it would, of course, be necessary to allow for the fact that the slope of the line is slightly different during picking up, owing to the effects at the bottom lagging behind the causes at the top, due to the resistance of the water. This rigorous solution is not attempted at present, owing to lack of knowledge of the water resistance. It is considered that the result of ignoring the lag in effects makes little difference to the conclusions, owing to the slowness of the operations. In practice, in the example taken, a point in the cable would take from 2 to 4 hours to pass from the sea bottom to the surface.

The conditions shown in Fig. 3 are reached, for all practical purposes, after a length of cable equal to several times the depth of water has been recovered. When picking-up is commenced with conditions as in Fig. 2, the cable comes inboard with a lengthened lay to the extent of $\frac{1}{2}$ turn per fathom. This causes screwiness, since when the cable is relieved of tension as it leaves the drum of the cable-gear, it endeavours to relieve the torsion due to its untwisted state by throwing turns. The screwiness will gradually disappear as the conditions of Fig. 3 are approached. In Fig. 3, however, the cable near the sea bed is twisted up to the extent of one turn per fathom, and hence the tendency to throw turns (and thus to kink) is increased as compared with Fig. 2.

If the angle the cable outboard bears to the bow sheave be changed so as to unlay the cable passing round the sheave to the extent of 1 turn per fathom, which can be done with the usual left-hand-lay cable by causing it to trend to port by the requisite amount, the conditions will gradually change until, as is inevitable finally, the cable passing inboard is of normal lay, the cable immediately outboard of the bow sheave is twisted up to the extent of 1 turn per fathom, and the cable near the sea bed is twisted up to approximately 2 turns per fathom. In the light of the earlier arguments this should be self-evident, since if the cable in passing round the bow sheave is being untwisted to the extent of 1 turn per fathom, and yet is of normal lay when it leaves the bow sheave (assuming no twisting action by the deck leads), it must have been twisted up to the extent of 1 turn per fathom before arrival on the sheave. Furthermore, the difference in tension at the top and bottom leads, as before, to there being approximately 1 turn per fathom more twist at the bottom than at the top. The final conditions under

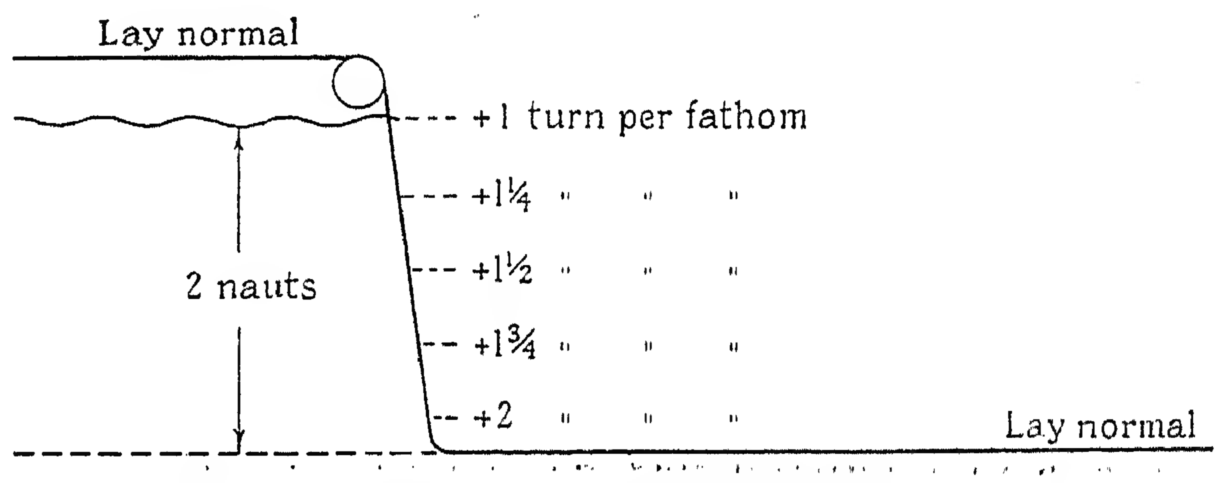

FIG. 4.—Cable being untwisted on bow sheave.

consideration are shown in Fig. 4. During the time the conditions are changing, screwiness will result as before, owing to the cable recovered being of abnormal lay. Owing to the cable near the bottom being twisted up to the extent of approximately 2 turns per fathom, the probability of kinking is far greater than when the bow sheave is not twisting.

If now the angle of the cable outboard is changed so as to lay up the cable passing round the sheave to the extent of 1 turn per fathom, which can be done with the usual left-hand-lay cable by an appropriate trend to starboard, the conditions will gradually alter until the cable immediately outboard is untwisted to the extent of 1 turn per fathom, the cable inboard then being of normal lay. The cable at the bottom, which by hypothesis is of 1 lay per fathom more than the cable at the surface, will now be of normal lay. These conditions are shown in Fig. 5. The normal lay near the bottom is the important feature of these conditions, since now, during pauses in picking-up (during which time there is no tension near the bottom due to the horizontal movement of the suspended cable), there will be no tendency for the cable to throw turns and thus to become kinked when picking-up is recommenced.

While the conditions shown in Fig. 5 were being approached from a previously different condition, screwiness of the picked-up cable might result, by virtue

of the fact that the picked-up cable must be of abnormal lay when the lay of the suspended cable is changing. The conditions shown in Fig. 5, however, are such that there is no torsion in the suspended cable, each portion of the latter being unlayed to the extent to which it naturally tends owing to the tension there. The condition of no torsion is such as would result if the cable were free to turn, so that such a condition could be obtained before commencing to pick up, by inserting an efficient swivel in the drum rope, and paying it out past the bow sheave. A swivel to which the adjective "efficient" would be applied, however, is not at present available in cable ships; the swivels used in grapnel rope would certainly be useless for this purpose. Ball- or roller-bearing swivels capable of being paid out over the bow sheave and of withstanding stresses of several tons should not present serious engineering difficulties, and it is possible that such are already in use in other branches of engineering. It would be desirable if possible to keep the cable trending out slightly from the vertical until the swivel was paid out, in order that there might be some tension at the bottom to reduce the likelihood of

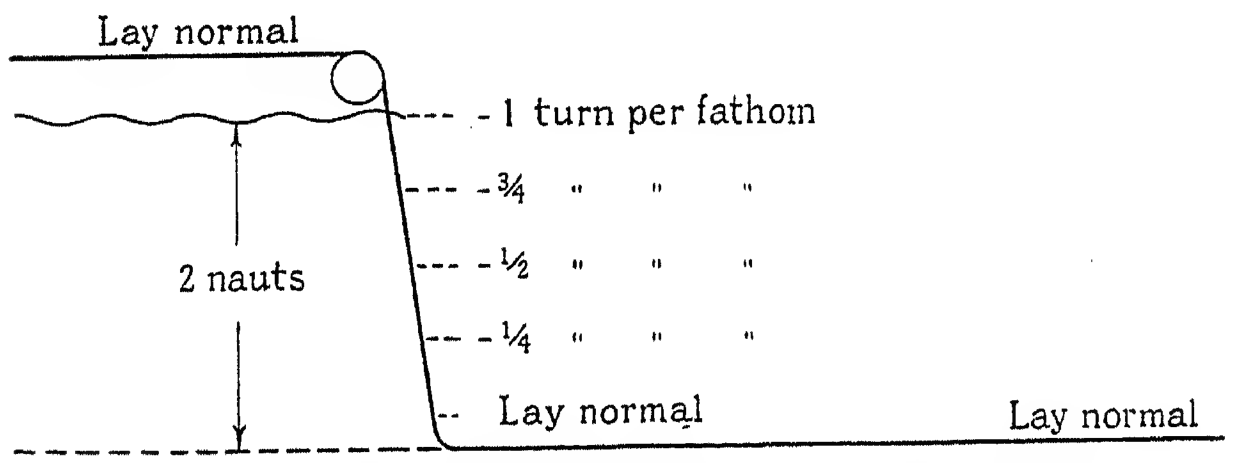

FIG. 5.—Cable being twisted up on bow sheave.

kinks forming before the action of the swivel became effective.

It is of interest to note that the upper end of the cable must revolve about 1 000 turns in order to change the conditions from those of Fig. 2 to those of Fig. 5. The possible heating of a swivel, or failure of a swivel to turn, could be largely guarded against by using several swivels in series. The friction of the water would, of course, limit the rotational speed of the cable whilst unlaying.

The conditions shown in Fig. 5 will continue throughout the picking-up process so long as the cable is kept trending to starboard by the appropriate amount. The cable passing to tank will be of normal lay, and therefore non-screwy, and the cable near the bottom will also be of normal lay, and therefore not conducive to the formation of kinks. This condition is therefore the one most likely to ensure the successful recovery of deep-sea cable, although slight differences and slight changes in conditions are not likely to be material.

Slight differences from the ideal will result in there being some torsion near the bottom during pauses in picking up, but this is unlikely to cause kinking, which results from the throwing of a turn together with sufficient torsion to prevent the turn from throwing back when the cable is pulled tight. Provided, therefore, that the torsion is small, the cable should pull straight without kinking. Slight changes from the ideal result in slight torsion in the cable passing to tank, but such is not likely to cause bad coiling in view of the torsional flexibility of the cable, a property which has in any case to be depended upon for coiling, since one twist per turn in the tank is necessary during this operation.

It is not insignificant that the desirable conditions (as shown in Fig. 5) are more likely to exist after using a cutting-and-holding grapnel if the grapnel rope be of opposite lay to the cable. After the grapnel has cut away the unwanted end, it is free to turn, and the torsional effects of the cable and the grapnel rope will both tend to turn the grapnel the same way. Cable is usually of left-hand lay and grapnel rope of right-hand lay, and in these circumstances a substantial unlaying of the cable will take place after the grapnel has cut. While measurements were being made at Greenwich in 1928 of the unlay of 15/13-type cable under stress (see page 162), a measurement was also made upon the common type of grapnel rope, composed of 18 steel wires of 0·106 in. diameter, served and layed up as three strands of 6 wires each. The rope was found to unlay $\frac{1}{3}$ turn per fathom when used for suspending a weight of 2 tons, and to recover completely when the weight was removed.

SUCCESSFUL RECOVERY OF CABLES.

The contention put forward, therefore, is that it is desirable that the cable and grapnel rope should be of opposite lay. This is opposed to what has sometimes been contended, that the spinning of the grapnel is objectionable in that the cable is likely to be twisted off. Some evidence of the useful effects of a cutting-and-holding grapnel combined with the opposite lay is furnished by the experience in repairing the Durban–Mauritius cable in 1928 in 2 000 to 2 500 fathoms, a repair which involved an expenditure of 100 nauts of cable. A good end was brought inboard four times; on two of these occasions the end was eventually lost after it had developed a fault due to kinking at the bottom, and on these two occasions it was found that a bight had been lifted. On the other two occasions a cutting-and-holding grapnel was used, and, after joining and splicing, successful pay-outs were made.

The lay of grapnel rope would be immaterial, so far as the effects under consideration are concerned, if an efficient swivel could be inserted near the grapnel. It is doubtful, however, whether a swivel which had to be dragged along the bottom could be depended upon to function satisfactorily. It is customary practice at present to insert swivels at intervals in grapnel rope, but their construction is such as to give very little hope of working under tension except with unusually high torsional stresses.

The argument so far outlined indicates that to recover deep-sea cable without screwiness it is necessary to maintain a constant amount of twisting by the bow sheave, and that to avoid kinking at the bottom it is necessary for the twisting by the bow sheave to be a particular amount. The requisite twisting by the bow sheave may be obtained in a variety of ways. With existing bow sheaves it is only possible to obtain it by keeping the cable trending to starboard by the requisite amount (assuming left-hand-lay cable), but this procedure is frequently very difficult owing to wind, sea, and set, and in any case is undesirable as it puts an unnecessarily

high tension on the cable. The excessive tension could be avoided by mounting a sheave at an angle to the vertical, so that the cable makes the requisite angle with the sheave when it is substantially "up and down." A further step would be the use of a sheave the angle of which could be manually adjusted to the required value, which would enable the angle to be altered to follow a change in angle of the cable from the vertical due to difficulties in the manœuvring of the ship.

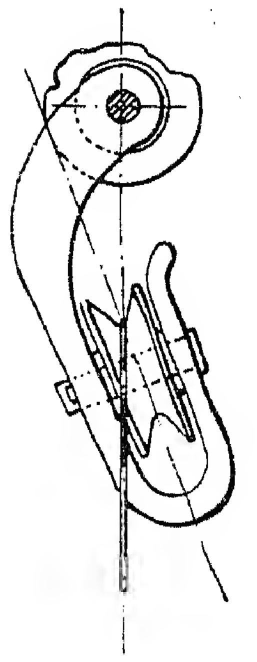

Fig. 6.

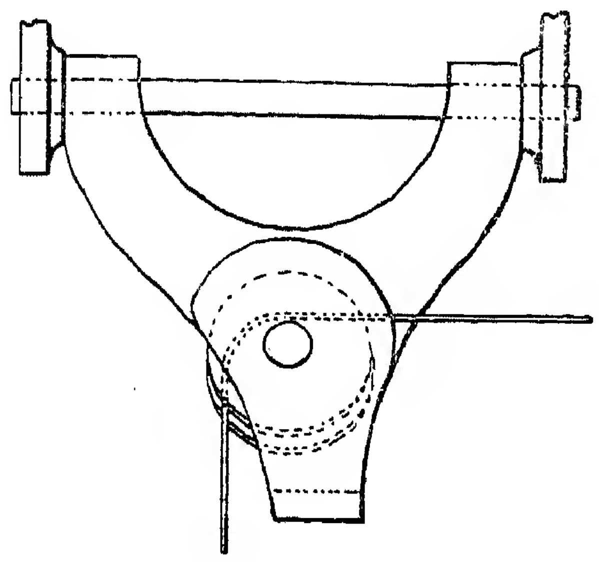

Fig. 7.

British Patent No. 319527, dated 25th October, 1928, describes alternative forms of swivelling sheaves by means of which the angle between the sheave and the cable could be made to remain substantially constant notwithstanding variations in the angle made by the cable with the vertical. One form is shown in front view and side view respectively in Figs. 6 and 7. The axis about which the sheave swivels is in line with the cable inboard, but set off to one side of the central plane in which the sheave revolves. The "set-off" causes a

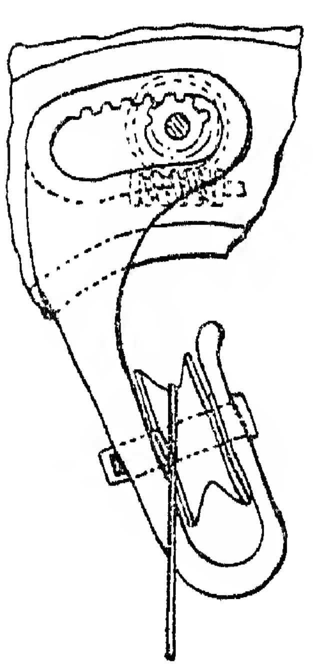

Fig. 8.

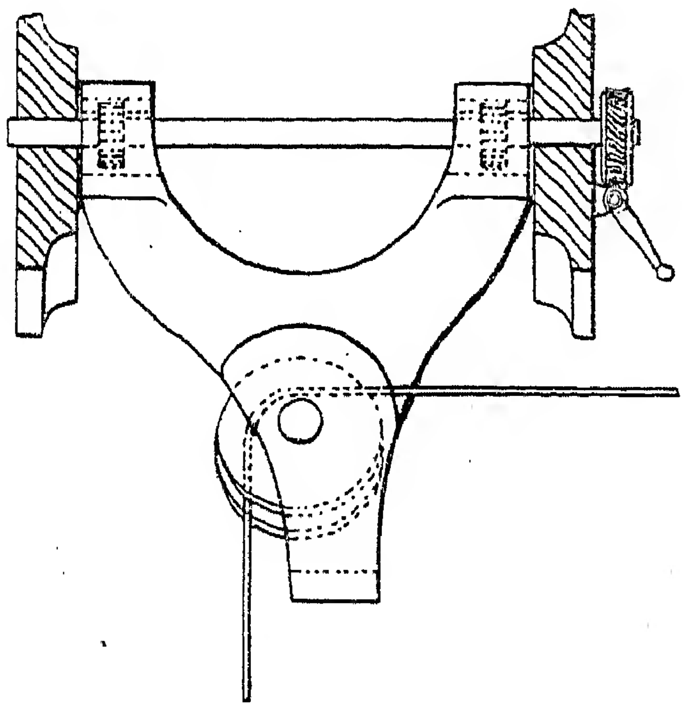

Fig. 9.

substantially constant angle to be maintained between the cable and sheave, as shown in Fig. 6.

Figs. 8 and 9 show an elaboration of the previous form of sheave, in which internal teeth in an arc-shaped slot in the upper part of the framework engage with spur pinions, the latter being rotatable by means of a worm and wormwheel so that the off-set of the swivelling-axis can be adjusted. The weight need not, of course, be taken by the teeth.

Design of Cable Ships.

It is usual practice to mount the sheaves in the overhanging bows of the cable ship, and there is a very good reason for this in that it is the best position for keeping the cable clear of the ship. When a bight of fairly tight cable in shallow water is hove up on the grapnel, the "legs" lead out either way at angles not far from the horizontal, and overhanging bow sheaves are almost essential for handling cable in such circumstances. In deep water, however, it is not possible to bring a bight of tight cable to the surface; unless a cutting-and-holding grapnel is used, it is necessary for one leg of the cable to end not many miles away so that it can drag in to provide the slack necessary to enable the cable to be raised. When cable reaches the surface from deep water, and during picking-up operations in deep water, it is not practicable to have the cable trending to an angle of more than 5° to 10° from the vertical on account of the undesirable increase in tension which would result. For deep-water operations, therefore, the bow position of the sheave is no longer essential, and this allows of the minimization of one difficulty which is accentuated by the bow position. This difficulty is the up-and-down movement of the ship due to "sea," and the position subject to the greatest movement is undoubtedly the overhanging bow. This vertical movement causes the tension on cable being picked up to rise and fall, and makes fair weather essential for the carrying-out of satisfactory deep-water work. During picking-up operations the main essential is that the maximum velocity of the vertical movement of the sheave due to "sea" should be not greater than the average speed at which the cable is being picked up (usually from ½ to 1 naut per hour), since the cable may pass into the ship irregularly whilst being lifted through the water steadily; but nevertheless, the inertia of the picking-up machinery and other considerations must cause the tension to rise and fall to some extent, so that the less the up-and-down movement of the sheave the better.

The best position for a sheave in order to obtain the minimum up-and-down movement is clearly in the centre of the effective length and the centre of the width of the ship, where the vertical movement due to "pitch" and "roll" would be least, but obviously such a position would necessitate radical changes in the design of the ship. A distinct improvement over present practice could be obtained, however, by the use of a sheave positioned well back towards the middle of the length of the ship. There would be no necessity to have the sheave in a fore-and-aft line; it could project over the side at any angle convenient with respect to other considerations.

It is to be noted that the sheave must be able to twist the whole length of the suspended cable. An outboard lead to guide the cable on to the starboard cheek of the sheave is inadmissible unless it gives the cable absolute freedom to turn, and such a condition is not easy of accomplishment.

The amount of twisting by the sheave necessary to avoid torsion in the suspended cable will depend upon the depth of water and type of cable. It may be calculated, knowing the characteristics of the sheathing and the dimensions of the cable, or it may be determined by experiment upon a short length of cable. For this experiment to be reliable, however, it must be somewhat elaborate. If the suspended cable has been allowed to

relieve its torsion by means of an efficient swivel, the twisting required is that necessary to restore the lay to normal as the cable is picked up; satisfactory coiling after the use of a swivel would indicate, therefore, that the amount of twisting was approximately correct. When a longitudinal marking has been left by the cable-making machine, any variation of the lay from normal can be observed.

The calculation and experiment to determine the tendency of cable to unlay under tension (see page 161) indicate that cable sheathed with No. 13 B.W.G. wires requires a twisting of about $\frac{1}{2}$ turn per fathom in a depth of 1 000 fathoms, and proportionally at other depths. Cable sheathed with No. 14 B.W.G. wire would require about 50 per cent more turning, owing to the much smaller torsional strength of the wire. It is probable that these approximations are sufficient for practical purposes, since it is not necessary to achieve the ideal conditions, and since—although the breaking stress of the wire used for the sheathing of deep-sea cable varies over a large range—the torsional elasticity of a number of samples measured has shown little variation other than is attributable to the diameter.

Nearly all the deep-sea cable which has been laid has been sheathed either with No. 13 or with No. 14 B.W.G. wire. It would be difficult to give any very convincing reason why one of these sizes is chosen instead of the other: No. 14 wire has been practically abandoned by some cable companies for many years, whilst it has been used by others comparatively recently. Although the question of torsional elastic limit was probably never considered, this feature of the cable places a limit to the depth from which it can be expected to be recovered without damage. There is a certain length of each type of cable which, when hanging freely in water, will cause the upper end just to unlay to the elastic limit. In depths greater than this length, the cable will be unlayed beyond the elastic limit, and coiling trouble is to be expected, although it is possible that the twisting action of the sheave might give an opposite and counteracting set to the wires. The length of cable which can hang freely without the upper end being twisted beyond the elastic limit will in general be greater the larger the diameter of the wires.

The formation of kinks near the sea bottom is undoubtedly the result of torsion in the suspended cable, but torsion does not necessarily lead to kinks. It frequently happens that when a stoppage has to be made (e.g. in order to oil the cable gear) after picking-up has been proceeding satisfactorily for some time, kinks will subsequently come inboard after a length equal to the depth of water has been recovered. The explanation is simple: during the picking-up process the suspended cable is moving horizontally through the water, which offers a resistance of such a magnitude that a considerable stress is added throughout the suspended cable. It is common knowledge that the picking-up tension is very considerably greater than that which exists when picking-up is stopped. The additional tension is to a small extent due to the longitudinal movement of the cable through the water, and this excess would die away towards the bottom; but most of it is due to the horizontal movement, which *does* appear at the bottom. This tension at the bottom will tend to prevent the throwing of turns, with consequent kinks. On occasions kinks have occurred for a time at regular intervals of about a fathom, and there is little doubt that this is due to the fact that the pitching of the ship causes the tension in the cable to slacken, enabling turns to be thrown at the bottom.

The additional tension throughout the suspended cable when picking up, due to the horizontal movement, produces a torsion (or an increased torsion); but, as pointed out, the tension at the bottom prevents the formation of kinks. The torsion, however, results in the difference in the lay between the top and bottom of the suspended cable being slightly less than when the latter is hanging still. The effect is not of great importance, as at most it merely means that the necessary twisting during picking-up is slightly less than is indicated when no allowance is made for the additional tension and torsion.

If cable passes into the tank with a normal length of lay (i.e. without twists or untwists) it should coil well, provided it has not been damaged. There is no evidence to show that soundly-manufactured cable can be damaged by tensions not far short of the breaking stress, but much cable has been damaged by being pulled round a sheave or lead of too small a diameter. The usual kinds of deep-sea sheathing-wire have elastic limits that are very low compared with that of spring steel, and the cable will therefore stand but a very limited amount of bending before showing a permanent set. There is room for improvement in the design of certain parts of cable-ship machinery to ensure that no damage occurs due to bending.

A few cable ships are fitted with what are usually termed "flat" bow sheaves. These have a cylindrical periphery with flanges each side, and render it necessary to keep the cable very nearly in the fore-and-aft line of the ship, otherwise it is likely to be seriously damaged upon the flanges or the "whiskers" covering them. Sheaves of this type permit very little twisting of the cable, and as this is a suitable condition in moderate depths of water very successful cable operations are performed with them in such depths. From the theory here put forward, it is apparent that the successful recovery of cable from deep water is not to be expected when using flat sheaves, not on account of bad coiling but owing to the formation of kinks at the bottom.

Effects in Shallow Water.

Trouble of the following kind, which is sometimes experienced in comparatively shallow water, would appear to show the effects of torsion. An end which, judged by electrical tests, is apparently sound is aboard, but, there is a kink on deck which has not exposed the copper owing to the tension not having been sufficient to pull it tight. Cable is picked up, but no sooner is the kink well inboard than another leaves the water, and this is repeated many times, even though the total length of cable picked up much exceeds the depth of water. Now the water is too shallow for a tension to be produced which would result in sufficient torsion to cause kinks. These may, however, be due to the twisting-up (shortening of the lay) of the suspended cable in consequence of the cable trending to port. The trending of the cable to

port is a condition to be avoided with all depths. It is probable that this particular trouble in shallow water has never been experienced with flat sheaves. A common explanation of kinking is that the cable has been laid with too much slack, but it is doubtful whether this alone, without the help of torsion, is a sufficient cause.

When cable is being paid out aft one often observes that it is turning to the extent of, say, $\frac{1}{2}$ turn per fathom, at the normal speed of 6 to 8 knots. In order to pay cable out with a certain percentage of slack, a tension is kept on it which is a certain amount less than the weight of a length of cable equal to the depth of water. This tension gradually falls to zero at the point where the cable takes the bottom, which may be about 20 nauts astern when the depth is 2 000 fathoms. The greater tension in the upper portion of the sinking cable causes it to unlay and lay up the lower portion, and the final condition—after paying-out has been proceeding for, say, some hours—is that as the cable leaves the sheave it untwists to a lengthened lay which gradually recovers to normal as the cable sinks. The upper portion of the cable will not be entirely free of torsion, since one cannot ignore the element of time. These conditions are widely different in degree from those which pertain during picking-up operations, when the length of cable between ship and bottom is about 10 times as great, and the cable speed relative to the ship is also about 10 times as great, giving a difference factor of about 100 : 1. In a mathematical examination of the problem it would therefore be necessary to introduce the friction of the water to the rotational movement of the cable. It is clear, however, that after a "pay-out" the suspended cable will have to some extent been freed of torsion, so that this effect is one factor upon which the chances of successful cable repairs depend. It is a factor which must be considered when drawing conclusions from practice: it means that there is less chance of trouble occurring at the bottom when hanging on to an end after paying out than when hanging on to an end which has been raised on the bight, unless in the latter case steps have been taken to relieve the torsion.

The theory developed in this paper has been confirmed in practice on numerous occasions during recent years, so far, at least, as to prove that for consistent good coiling without kinking the cable must be kept trending to starboard at the appropriate angle. That the cable would eventually coil well (apart from kinking) after picking up for a time with a trend to port or with no twisting action by the sheave, has not been proved owing to the prohibitive cost of the experiment. Not only would this involve the crippling of several nauts of valuable cable, but the breakage of the cable due to a kink would result in a loss of time amounting quite easily to days.

A prominent case of successful recovery of deep-sea cable was that of the C.S. "Cambria," when undertaking an extensive repair in the Western Atlantic in 1930, following a serious subterranean disturbance. Preparatory to effecting a diversion of route, nearly 200 nauts of cable were recovered from deep water, much of it being over 2 000 fathoms in depth. Less than 8 per cent of the cable was found to be unfit for re-laying.

It might be objected that if the considerations put forward in this paper really applied in practice, successful cable operations in deep water during the last 50 or more years would be a rare exception. The reply to this is that, in the first place, the recovery of considerable lengths of deep-sea cable has seldom been attempted, and, in the second place, that during repairs conditions approaching the ideal can be obtained without any special endeavour being made to that end.

Conclusion.

In conclusion, the authors have to admit that this paper is incomplete in some ways. The apology for this is that new ground is being broken, and that though there is clearly room for further mathematical investigation, it is doubtful whether such could be usefully interpreted until further practical data were available on such subjects as the resistance of water to the rotational, longitudinal, and perpendicular movement of cable. There is no doubt, however, that the application of the theories put forward in this paper will remove, as they have commenced to do, much of the inexplicable which attends deep-sea cable operations. Nevertheless a strong element of luck combined with skill is bound to remain in an art where factors of safety are only a fraction of those common in engineering practice generally, and where the weather can so accentuate the difficulties.

A RADIO-FREQUENCY BRIDGE FOR IMPEDANCE AND POWER-FACTOR MEASUREMENTS.*

By D. W. Dye, D.Sc., F.R.S., and T. Iorwerth Jones, B.Sc.

[From the National Physical Laboratory.]

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Summary.

The paper deals with the problems which arose in the adaptation of the Schering bridge network for service at radio frequencies, and describes the final form taken by the arrangement of components, screened high-frequency source, and screened detector-amplifier, which has given a satisfactory performance at frequencies as high as 1 million cycles per sec. The steps which had to be taken to ensure a simultaneity of the main and the auxiliary bridge balances and to expedite the convergence of the succession of balances upon the final simultaneous balance are explained.

An account is given of the modifications which have been introduced into the well-known Schering bridge network, and of the provisions which had to be made in the disposition and the linking-up of the component parts to render the bridge capable of precision measurements.

The arrangement described is essentially an equal-arm bridge composed of two capacitance arms, two resistance ratio-arms, and two auxiliary resistance ratio-arms, the latter forming part of a Wagner earthing system. The resistance arms are provided with condensers in parallel for phase-angle adjustments. Tappings are brought out in the main arms which permit of a choice of resistance for the whole arm and for the fraction across which the condensers are shunted. The artifice of connecting the power-factor-measuring condenser across only a fraction of the main resistance was adopted in order to supply a means of maintaining the changes of capacitance which are required when dealing with a large variety of power-factor differences over a large range of frequencies, always of the same convenient order of magnitude.

The procedure followed in the measurements is strictly one of substitution of a variable air condenser for an actual, or an effective, capacitance of approximately the same value. Apparatus such as coils are tested in series or in parallel with such a value of the capacitance in the arm as brings the effective capacitance of the composite arm to the value required for a bridge balance. Observations are taken of the change in reading of the standard air condenser and of the difference in setting of one of the power-factor-measuring condensers required by the inclusion and the exclusion of the impedance under test. From these two differences the two components of the impedance may be computed. In the case of condensers, the condenser is replaced by the variable air condenser. The capacitance is obtained directly from the settings of the latter. The power factor is derived from the formula

$$\Delta\theta = \frac{1}{\rho^2} R \Delta C \omega \frac{K_T}{K_S}$$

where R is the resistance of the ratio-arm, and $1/\rho$ is the fraction across which the difference ΔC is observed. K_T represents the total capacitance forming the arm, and K_S the substituted capacitance under test. The corrections to the simpler formulæ, when the ratio-arms and the arm under measurement possess large phase angles, are discussed and evaluated. In order to reduce the phase angles of the resistance arms to a minimum, the latter have been provided with a shield, independently earthed, in preference to a separate screen connected to their common point.

The successful performance of the arrangement is to be attributed in the first place to the attention which has been given to the design of the high-frequency screened source and of the detector-amplifier, and secondly to the arrangement of the component parts of the network and of the system of wiring which has been developed. The adoption of toroidal forms for the tuning coils of the source and of the high-frequency stage of the amplifier, together with the screening arrangements employed, has practically eliminated all stray inductive and any capacitative coupling between the source and the bridge arms or the amplifier, respectively. Reversal of the leads from the source at 1 million cycles per sec. affects the power-factor balance by only $0{\cdot}00000_2$.

In approaching the final balanced state of the bridge, the usual procedure is followed of adjusting two vectors in the main network for a balance of the main bridge, alternately with the adjustment of two vectors in the Wagner earthing system for balance of the auxiliary Wagner bridge. In practice a large number of alternations have to be made. The fewer that are necessary, the more convergent is the balancing process. The entry of parasitic voltages into the detector system (which is inconsistent with a condition of simultaneous balance of both systems) was found to retard the process very seriously, and when the impedances composing the bridge arms exceeded a certain value the process even became divergent. Consequently, the detector points of the main bridge, and the Wagner bridge, respectively, have been brought close together, and the whole detector circuit has been so designed as to contain no open loops. All exposed points in the amplifier have also been carefully screened. In order to ensure satisfactory conditions for convergence it became necessary to connect the filament of the input stage of the amplifier to the detector point located at the junction of the capacitance-arms. The grid is therefore transferred between the two remaining detector points in the course of the balancing alternations. It was discovered that the convergence could be regulated and further improved by the suitable choice of a resistance which is inserted across these detector points at the amplifier end. The bridge thereupon became easily workable, and the balance was found to be almost independent of the values of the impedances connecting the detector points to earth. The potentials of all three detector points are therefore very close to earth potential.

In its present form it is considered that the bridge arrangement is capable of measuring, to an accuracy of 1 per cent, power factors lying between the limits 0·001 and 0·1, and

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differences in power factor of precision air condensers to an accuracy of 0·00001 at all frequencies up to 1 million cycles per sec.

The paper concludes with a list of a.c. measurements for which the bridge is recommended.

A solution of the general bridge equations, taking account of impedances from all four corners of the network to earth, is included as an Appendix.

TABLE OF CONTENTS.

(1) INTRODUCTION.

At telephonic frequencies bridge methods have almost completely superseded the older deflection methods for precision a.c. measurements. The advantages which they offer, in common with most null methods, over the majority of others which have been developed for radio-purposes, suggested that, with suitable arrangements, they could be developed for use well above the usual telephonic frequency range. Unlike resonance methods, which depend upon direct observations of voltage or current, bridge methods are not hampered or rendered unduly tedious by the unsteadiness which usually characterizes the output of valve oscillators. For this reason they are capable of greater precision and are thus less dependent on external conditions. When using other methods considerable coupling, often of an indefinable character and depending upon the external field of the source, is normally required between the source and the circuit under test; but in a bridge circuit the current can be supplied through a fixed system consisting of definite impedances. By the introduction of toroidal coils into the source supplying power to the bridge network, extraneous coupling is eliminated, together with the errors associated with variations in the amount of coupling to the source, which are frequently necessary in the course of the measurements in a number of methods.

Bridge methods also possess the advantage that, when a tuned detector is used, the balance condition is solely a function of the fundamental component of the wave-form of the voltage supply, so that they preserve all the advantages of the selectivity of resonance circuits without entailing the risks of introducing parasitic voltages into the measuring system. These risks are considerably greater with the open-wound coils which have to be employed in order to introduce the necessary power into the circuit and to keep its decrement as low as possible. With the aid of modern detector-amplifiers, the sensitivity of the bridge method can be made sufficiently great for most practical requirements. There is, finally, an additional reason for the development of bridge methods to serve special needs at radio frequencies. Three-terminal pieces of apparatus have to be dealt with and, in certain circumstances, they are of great service. Up to the present, the bridge system alone is capable of dealing satisfactorily with measurements on such apparatus. One valuable application is the measurement of the properties of dielectrics at radio frequencies.

Prior to the year 1927, in which the work of designing the arrangement described in the present paper was first commenced, the applications of bridge circuits to the conditions peculiar to radio frequencies had made little progress, and very little had been published on the subject. Beyond a short preliminary note by Englund,* dealing briefly with the results obtained in America, and the early work of Hart† in this country, no relevant information had appeared. In the meantime various bridge networks and the schemes of construction which are necessary to render them workable and efficient at low radio frequencies, have been published in America by Stratton,‡ Shackleton,§ Ferguson,|| Bartlett,¶ and Boner.** Two systems evolved in Germany for industrial purposes have been described by Küpfmüller†† and Schlesinger.‡‡ The majority of these investigators have followed independent lines, which are quite distinct from that described by the present authors. It is not proposed to enter here into any discussion of the relative merits of the various electrical systems which have been put forward.

(2) PROPOSED BRIDGE NETWORK.

(a) General.

The choice of the Schering-bridge network for radio-frequency measurements was influenced by the consideration that the component parts were restricted to condensers and resistances, and that it supplies a continuously variable means of making phase-angle adjustments. With the adoption of toroidal forms for the coils forming part of the tuned oscillatory circuit of the generator and of the tuned high-frequency stage of the amplifier, it has been possible to reduce to a very low value any stray coupling to or from such open-wound coils as the

* See Reference, (1). † *Ibid.*, (2). ‡ *Ibid.*, (3). § *Ibid.*, (4). || *Ibid.*, (5). ¶ *Ibid.*, (6). ** *Ibid.*, (7). †† *Ibid.*, (8). ‡‡ *Ibid.*, (9).

bridge may be required to measure. The elimination of capacitive coupling presented no serious difficulties.

Whereas the electrical circuit corresponds in general to the Schering network,* it has been found necessary to introduce a number of modifications to satisfy the different conditions which have to be met. In its original form the Schering bridge was primarily designed to work at ordinary commercial frequencies and to meet high-voltage conditions. As high voltages were not contemplated it was considered more suitable to interchange the positions of source and detector in the bridge as illustrated in Fig. 1, placing the condensers in series across the supply. A Wagner earthing system has been provided to ensure that the necessary conditions for the elimination of the effects of earth impedances from the corners of the bridge network were being continuously observed.

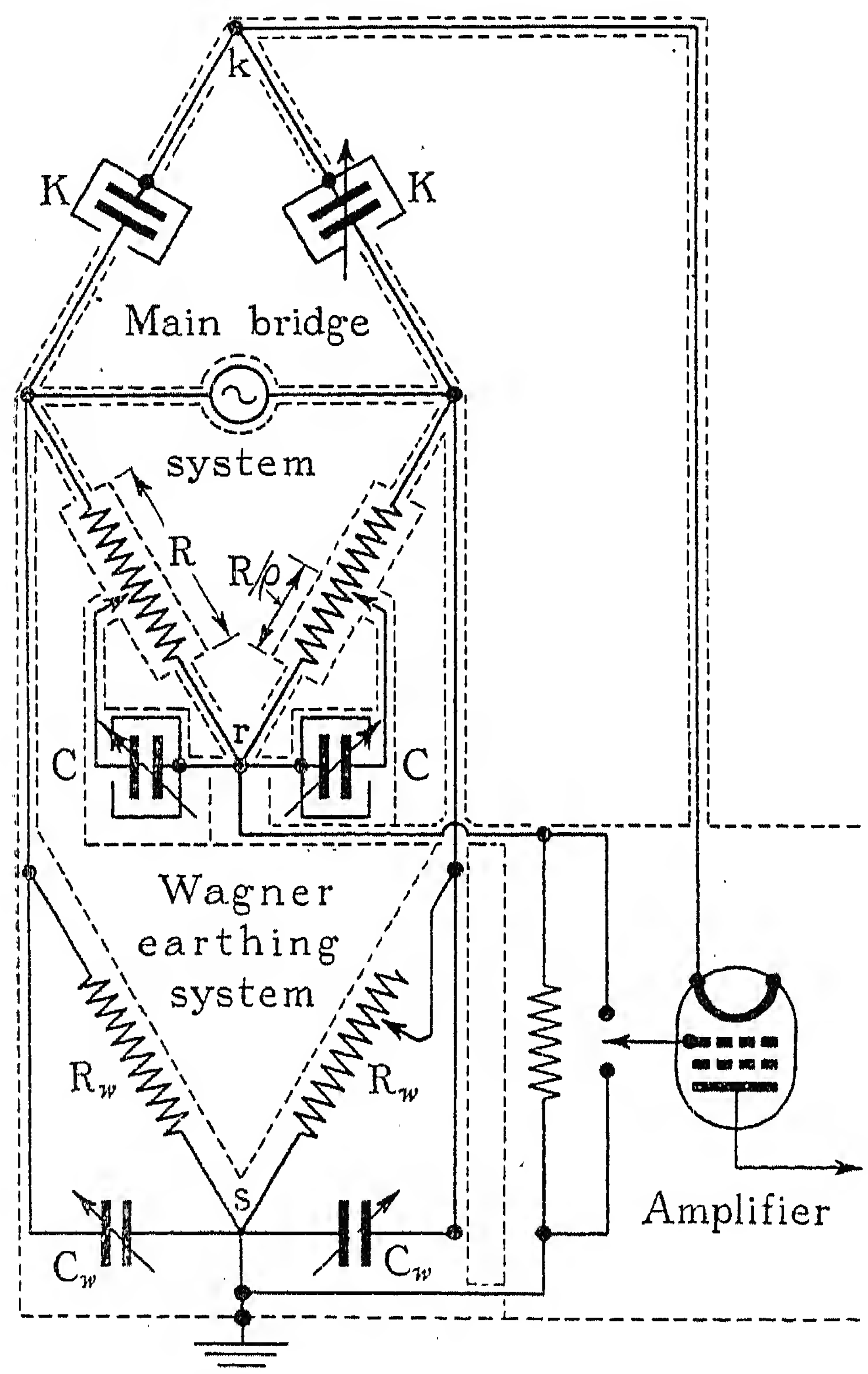

FIG. 1.—Radio-frequency Schering-bridge network.

The mid-points of each of the three parallel circuits are brought to the three bridge detector points, k, r, and s respectively, the mid-point of the Wagner resistance arms (R_w) being directly connected to the metal cover forming the earthed shield of the component parts, which is indicated by dotted lines. The main resistance arms (R) have tappings brought out which admit of a choice of resistance for the whole arm and for the section across which the condensers (C) are shunted. It is to be remembered that the use of unequal ratio-arms has been consistently avoided, and that the resistances and the capacitances occupying the left and the right arms of the network are approximately equal in magnitude. For this reason the two condensers forming the capacitance arms have been labelled K; those shunting a known fraction of the main resistance arms C; and those shunting the resistance arms of the Wagner earthing system C_w.

In preference to relying on the equality of the ratio-arms of the network, it was found advisable to rely upon a direct substitution in the same capacitance-arm. If the capacitance and power factor of a condenser are to be determined, the condenser is replaced in the arm by a variable air condenser of good quality. The setting of the condenser gives the capacitance, and the power-factor adjustments give the power factor in terms of the air condenser as standard.

(*b*) *Bridge Balance Conditions.*

To develop the main bridge-balance equation it will simplify the calculation to assume that the adjustments are carried out in adjacent arms, the procedure being somewhat as follows. Assume, for example, that the capacitance (K_1) and the power factor (θ_1) of one condenser are to be determined by comparison with and substitution in the left-hand capacitance-arm against a standard variable air condenser of capacitance K_2 and power factor θ_2. All cases for which the bridge is used resolve themselves into such a comparison as that to be considered. The left-hand arm is always adjusted to remain capacitative, and, approximately, in equality with the right-hand arm, whether K_1 be taken to represent a condenser proper, or a combination of an inductance coil and a condenser, which behaves as an effective capacitance of the same value. Whether the coil is in series or in parallel is of no account. The properties of the coil can be deduced from that of the composite arm. A variable air condenser K of power factor θ is placed in the right-hand capacitance-arm and serves to preserve the equality of the capacitance-arms in the process of obtaining the first bridge balance with K_1 in the left-hand arm. The phase-angle (or power factor) adjustments are made throughout upon the left-hand condenser C, termed the power-factor-measuring condenser, which is connected across the appropriate fraction ρ of the resistance arm R, the effective resistance of which can be assumed to change from R_1 to R_2, and the tangent of its phase angle from ϕ_1 to ϕ_2, in consequence of the adjustments which require to be made to re-establish a balanced condition of the bridge, on replacing K_1 by K_2.

The approximate condition $R_1 = R_2$ holds with sufficient accuracy, provided the phase displacements involved are small. In that case the relations connecting K_1 and K_2, and θ_1 and θ_2 are:—

$$K_1 = K_2$$

$$\theta_1 - \theta_2 = \frac{R(C_2 - C_1)\omega}{\rho^2}$$

where C_1 and C_2 are the settings of the power-factor-measuring condenser C corresponding to the insertion of K_1 and K_2 respectively in the capacitance-arm.

θ_1 used in the formulæ for power factor is to be considered synonymous with $\tan\delta$, where δ is the comple-

* See Reference, (10).

(*a*) *The Bridge Arms and the Wiring.*

All the component parts of the bridge network, with the exception of the condensers K and C (Figs. 1 and 2), are enclosed in a copper-covered box, as shown in the centre of Fig. 2.

The ratio-arms of the main bridge network consist of resistances of 1 000 ohms, which are isolated from the screen and are made up of units specially wound on mica cards to have very small residual inductances, commencing from the centre outwards (Fig. 2), of the values 10; $10\sqrt{10}$–10; 100–$10\sqrt{10}$; $100\sqrt{10}$–100; 1 000–$100\sqrt{10}$ ohms. On both resistances a tapping from each junction between adjacent units is brought out to two mercury cups lying, one on an arc of a circle with the top isolated mercury cup as centre, and the other on an arc with the cup below as centre. The cups lying on the arcs are Wagner earthing system; and (3) along the two parallel leads contained in the upper half of the T-shaped, projecting, metal tube, which is screened from the lower half, to the insulated terminals to which the condensers K are connected.

On the left side the Wagner earthing system consists of a fixed 2 000-ohm resistance, and on the right of a fixed 1 000-ohm coil in series with a good low-inductance decade resistance box with dials of 100, 10, 1, 0·1 ohms, and a still finer adjustment in the form of a sliding, tapered arc carbon dipping into mercury. The latter expedient proved the most satisfactory for final adjustments of the resistance vector independently of the quadrature component. Variable condensers C_w, with a range of 150 $\mu\mu$F, are connected across each of the Wagner resistances R_w. A spindle carrying a single

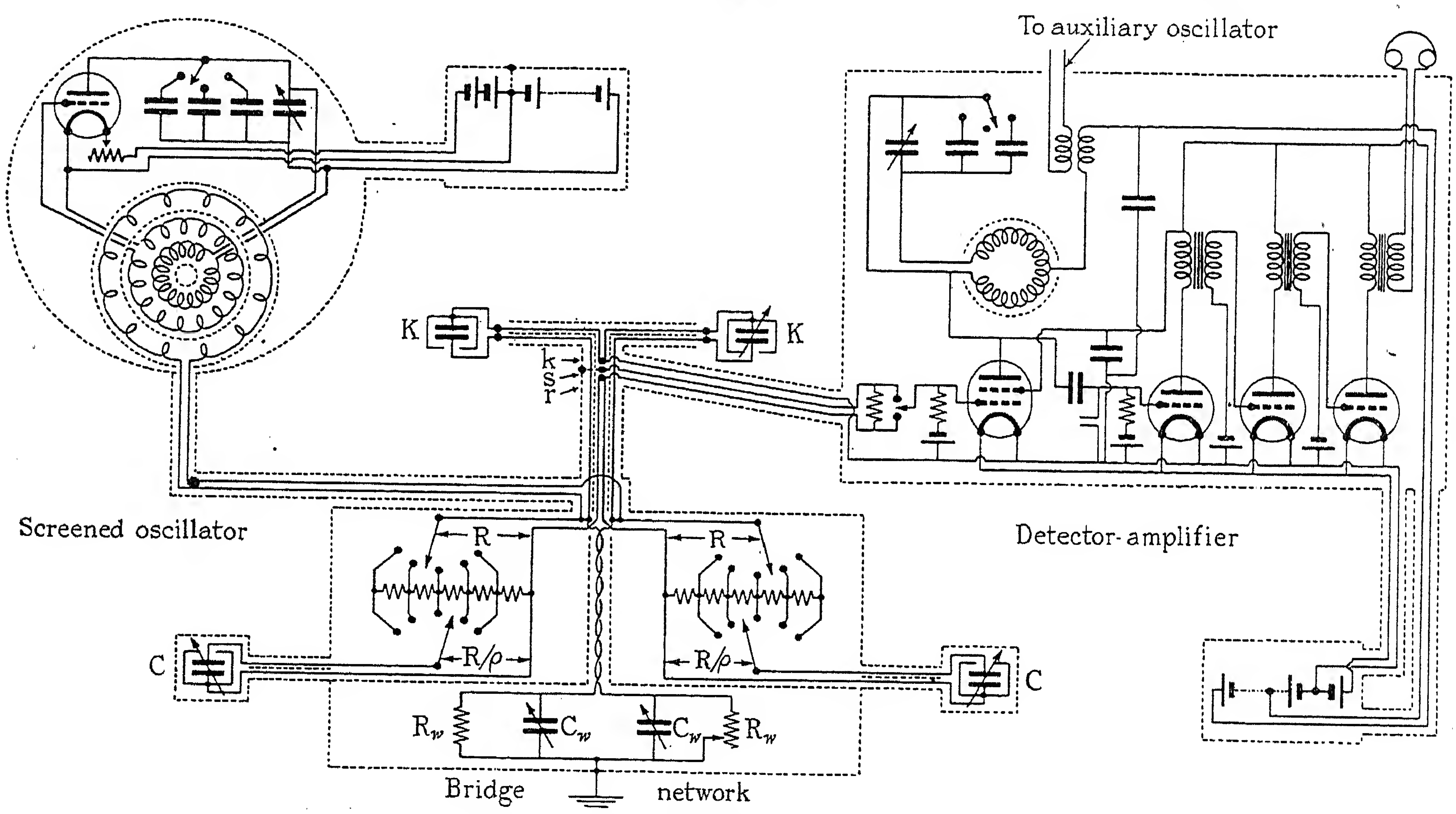

FIG. 2.—Radio-frequency Schering bridge.

connected at will to their centre cup by means of a copper link, which connects the upper set to one of the supply terminals of the bridge network, and the lower set to the insulated terminal of the appropriate condenser C. A hinged lid gives access to the links. In this manner the upper link permits of a choice of bridge arm from amongst the values 10, $10\sqrt{10}$, 100, $100\sqrt{10}$, and 1 000 ohms, and the lower link admits of as wide a choice of the portion of the arm across which the condenser C is to be connected. These condensers are housed in separate shields, which are in direct metallic connection with the main shield. The leads to them are brought out in braided copper sheathing, which is also earthed.

The screened plug and socket from the supply are situated at the centre of the back of the box, and from them the current divides into the three circuits: (1) along the links to the bridge resistances on either side; (2) along twisted, screened leads into the front compartment of the main box, screened from the bridge ratio-arms, to the small plate is fixed in the box near the right-hand corner and is insulated from the outer cover. The capacitance from this plate to the case is thrown in parallel with the right-hand condenser C_w and provides a fine adjustment of the reactance vector. The common point of the Wagner ratio-arms is directly connected to the metal box.

The third pair of arms consists normally of two air condensers, represented by K, situated at the extreme ends of the T-tube. The leads from the supply plug are kept close together and are carried inside the upper screened half of the tubes, which are about 5 cm in diameter. They end on either side of the T-limbs. The screens of the condensers, if they are of the two-terminal variety, are connected on either side to terminals associated with two leads which converge on the farthest of three points, k, near the union of the limbs of the T-tube. These leads are screened throughout their length from the supply leads and do not add

capacitance to the main capacitance-arm. They converge on one of the three corner points of the bridge, which is maintained at earth potential. In Fig. 1 this is the top detector point. The bottom detector point, which is earthed, is in metallic connection with the main shielding system. In Fig. 2 this is represented by s. The third detector point is r, which corresponds to the common point of the main resistance arms. The inner ends of each ratio-arm are brought out to r inside the lower half of the T-tube by a pair of stout parallel leads, disposed in a plane at right angles to, and screened from, the supply leads. The arrangement was adopted to meet the necessity of reducing to a minimum any possibility of the formation of loops by the connections in the vicinity of the detector points, which would be liable to induce voltages into the detector circuit itself. This accounts for the removal of the detector points to a safe distance from the resistance arms. The screening of the leads to r is most essential.

It remains to describe the detector system. The three points which have to be maintained at the same potential have been concentrated as near together as possible at k, s, and r. Sockets have been attached to each junction, and a screened plug has been designed which puts them into contact through a triple, flexible, screened lead with the input compartment of the valve amplifier. One detector point on the main bridge is permanently connected to the filament terminal of the amplifier. The other two detector points are connected to two studs. A selector switch puts either at will into metallic connection with the grid of the high-frequency valve. With the switch in one position, connected to r, the balance is obtained on the main bridge, and in the other, connected to s, on the Wagner auxiliary bridge. In Fig. 1 a resistance is shown connected across the two studs referred to above. This resistance, while not an essential part of the bridge network, is included for the purpose of accelerating balancing operations. The object which it serves is explained more fully in Section (5).

(*b*) *Screened High-frequency Oscillator.*

The source is assembled in a cylindrical all-metal box 25 cm in height and in diameter respectively. The oscillatory circuit employed is of the tuned-anode variety. The most important feature of the design is the adoption of the toroidal form for the inductances (Fig. 3). All three windings are wound separately on the same toroidal former, the output winding being screened capacitatively from the grid and the anode windings. The procedure followed and the details of the construction are included in Appendix I.

A set of six of these coils have been constructed, which serve in conjunction with a variable condenser of $0 \cdot 001\,\mu$F and three fixed mica condensers, each of $0 \cdot 001\,\mu$F, to cover a frequency range extending from 10 to 1 200 kilocycles per sec. The normal output of each of these coils, when an LS5 valve having 150 volts on the anode is introduced into the oscillator, is of the order of 20 volts (R.M.S.).

The general arrangement and the approximate disposition of the parts of the generator will be clear from Fig. 2. The batteries have a point earthed and are housed in a separate screened box. They are connected to the oscillator through screened leads. Two lids give access to the valve and the coil. The coupling to the output coil is entirely due to mutual inductance, the winding being almost completely confined within its own earthed screen and symmetrically disposed with respect to it. The output is conveyed to the bridge network by means of leads enclosed in braided copper sheathing. The result of the design is that on reversing the connections of the supply leads from the output

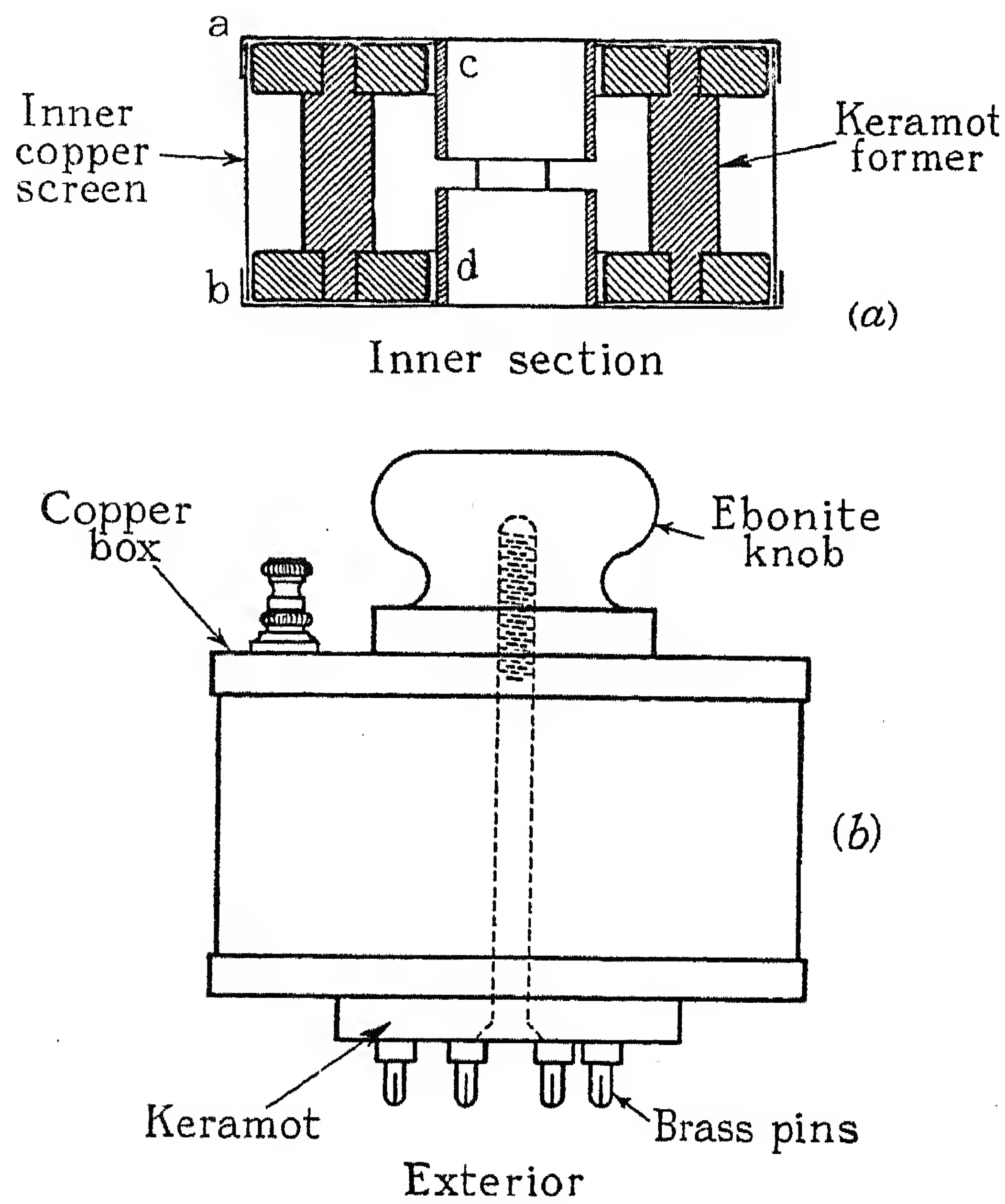

FIG. 3.—Screened toroidal coils.

winding to the bridge terminals at a frequency of 1 million cycles per sec., the power-factor adjustment is not found to be affected by more than $0 \cdot 000002$.

(*c*) *Screened Bridge-Amplifier.*

The amplifier consists of one tuned high-frequency amplifying stage and one rectifying stage, followed by two low-frequency amplifying stages. The high-frequency stage includes a screen-grid valve provided with a tuned anode circuit in which the inductance, as in the case of the source (*b*) above, is toroidal in form. Each of the six coils required for the range of frequency concerned carries the same number of turns as the anode winding of the corresponding coil of the generator. The centre point of each winding is brought out to one of three pins which are mounted on the copper box forming the outer screen of the coil. Two fixed condensers, each of $0 \cdot 001\,\mu$F, are provided for tuning purposes, together with a variable air condenser of $0 \cdot 001\,\mu$F having a fairly open scale.

The input from the auxiliary source, described under (*d*) below, which provides the heterodyne beat note, is introduced through the small transformer, the secondary of which is indicated at the low-potential end of the anode circuit of this stage. The provision of a separate screened input winding upon the toroidal inductance,

similar to the output winding of the generator, would permit of a greater measure of screening.

The high-frequency stage is coupled to the rectifier through a condenser. When a difference of potential existing across the bridge is applied to the grid-filament circuit of the first stage, a voltage of audible beat-note frequency will result from the rectification and will be transmitted by the low-frequency stages of the amplifier to the output transformer, across which the headphones are connected. The general features of the low-frequency amplifying stages will be seen from the circuit diagram and call for no comment. The batteries are housed in a separate metal box and are as completely screened as the amplifier itself. In the case of the latter, the projection through the outer cover of spindles of condensers and of switches, which are connected to points at a high potential, has either to be avoided or the spindles must be completely screened, as they are especially liable to pick up parasitic voltages and inject them directly into the anode circuit of the high-frequency stage. The aluminium box which houses the amplifier is isolated electrically from its circuits and forms part of the general shield of the bridge proper.

(*d*) *Auxiliary High-frequency Source.*

The auxiliary high-frequency source is not shown in Fig. 2. No special generator was constructed for the purpose. It is necessary that it should cover the same frequency range as the main source. Frequency adjustment from outside the case is desirable, and the coupling to the amplifier circuit should be variable so as to provide a ready means of controlling the input. It is necessary to enclose it in an earthed metal screen and to provide it with its own set of batteries. In practice there is an optimum input which should not be exceeded. The source should have the common point of the batteries connected directly to the screen.

(4) ELECTRICAL FACTORS OF IMPORTANCE IN THE DESIGN.

The nature of the problem of design from the electrical standpoint, together with the main reasons underlying the form which the bridge assembly has assumed, will become clear from the consideration of (*a*) the choice of connection of the amplifier, (*b*) the suppression of parasitic voltages, and (*c*) the elimination of extraneous impedances.

(*a*) *The Connection of the Amplifier to the Bridge.*

The three detector points of Figs. 1 and 2, k, r, and s, have to be brought to the same potential, namely, earth potential. Two balances have to be obtained by reducing to zero the potential differences between any two of these points, taken one at a time, and a chosen third. This implies in general that the other two may be referred to any one of the three corner points. There is still open the alternative whether to connect the fixed reference point to the filament or to the grid of the first valve of the amplifier. The choice therefore lies between six different possibilities.

The course finally adopted was decided partly by theoretical considerations and partly by experimental evidence. In the first place there is the inevitable assumption that the transference of the grid of a valve between two potential points involves less disturbance than the transference of the filament, which has the large earth capacitance of the batteries associated with it. Thus the field is narrowed down to three practical solutions.

Connecting the filament to s and anchoring the batteries directly to earth appears to be a most attractive solution. The chief objection to this procedure rests on the score that no *direct* comparison is made of the potentials of k and r, the equality of which is the essence of the development of the main bridge equation. Provided a true simultaneity of balance in both networks, across both reference bridges, is secured, the objection to this mode of connection disappears. On the other hand, it should be borne in mind that, in the absence of simultaneity of balance, no system of balancing is really satisfactory. Each system adopted will give different values, according to the summation of the parasitic voltages in any individual case. Up to now, for the reasons stated, this mode of connection has not been adopted.

The choice therefore lies between connecting the filament to k or to r. Experiment decided between them. A capacitance to earth from the common point of the ratio-arms, r, was found to retard the rate of convergence of the two bridge balances upon the unique condition of absolute simultaneity. The filament had, therefore, to be connected to k, and the grid had to be made to swing between r and s. The bridge balances are therefore taken on the bridge networks containing the condenser-arms and the bridge ratio-arms, and the condenser-arms and the Wagner ratio-arms, respectively, the points bridged being kr and ks.

(*b*) *The Elimination of Parasitic Voltages* (*including a discussion of the simultaneity of balances*).

Parasitic voltages may arise (1) by inductive coupling to the detector leads or to coils in the amplifier, and (2) by capacitative coupling to the amplifier.

As long as coils and loops are present in any part of a network, voltages will be induced in certain parts of the circuit, the effects of which are difficult to assess and which involve the measurements in numerous reversals before the errors which they introduce can be completely eliminated. This is particularly the case when measurements upon open-wound coils have to be made.

After what has been demonstrated about the high-frequency source, it will be appreciated that induction from the source could not be reduced much further. Among the other factors which were mentioned in discussing the location of the detector points, was the existence of loops formed by the conductors leading to the amplifier, which are threaded by fields produced by the currents flowing to and from the condenser-arms of the network. Should these currents not be exactly similar before and after substituting one condenser for another, the two voltages induced into the detector circuits would be unequal and would vitiate the results of the substitution. Even in the absence of such a want of symmetry, however, the presence of any parasitic voltage induced in the detector leads implies of necessity the absence of a simultaneity of balance, which after all is the primary postulate in the equations. A null reading

at the amplifier end is only indicative of an equality of potential at the detector points so long as no induced parasitic voltage is present in the lead system, and, in the second place, so long as there is no capacitative or inductive coupling directly into the amplifier. To obviate the former, the selector switch was removed to the amplifier end so as to withdraw it from the vicinity of current-carrying leads. The existence of the latter can be detected from observations of the behaviour of the amplifier.

When obtaining a balance the auxiliary oscillator is set at such a frequency as to give in the headphone a beat note which, to obtain optimum sensitivity, may be made to coincide with one of the resonances of the diaphragm. The tuning condenser of the amplifier is then adjusted to make the sound heard in the headphone a maximum. The process of balancing is continued until what are presumed to be simultaneous bridge balances are obtained. If on de-tuning the amplifier a sound reappears on either side of the original setting of the tuning condenser, it may be presumed that some parasitic voltage is getting into the anode circuit of the high-frequency valve. The toroidal form of the amplifier coil satisfactorily eliminates any inductive coupling. Against capacitative coupling there is no safeguard except adequate screening of exposed parts.

The criterion of the absence of parasitic voltages from the detector system is the preservation of simultaneity of balance at the detector points themselves. This can be most easily tested by connecting a variable air condenser between the common point of the capacitance-arms and the shield, and varying its capacitance. If the balance is unaffected, it must signify that that unique state of affairs has been realized where the main bridge balance is truly independent of the impedances to the shield from the corners of the network. Results of such a test on the present bridge at a frequency of 1 million cycles per sec. are shown in Table 2.

TABLE 2.

Frequency	Added capacitance, C_{ks}	Bridge capacitance, K	Power-factor capacitance, C	Power-factor change
kilocycles/sec.	$\mu\mu$F	$\mu\mu$F	$\mu\mu$F	
1 000	150	204·0	107	
	500	204·0	103	1×10^{-5}
	1 000	203·9	109	$0{\cdot}5 \times 10^{-5}$
	1 500	203·8	114	2×10^{-5}

Thus at 1 million cycles per sec. a change in reactance between a detector point and earth from 1 000 to 100 ohms produced a change in the power-factor balance of less than 0·00002, and a change in the capacitance balance of barely 1 in 1 000. This may be considered to represent a very close approximation to the desired state of simultaneity of balance. These deductions were also borne out by observations obtained with the use of a variable resistance R_{rs}, connected between the other detector point, r, and the shield.

It would be presumed that the presence of parasitic voltages in the detector system would, in addition to vitiating the final result, complicate the process of arriving at truly simultaneous balances. They will be found to retard the convergence of the two bridge balances. This aspect of the matter is dealt with in Section (5).

(c) *The Elimination of Extraneous Impedances.*

The effects of extraneous impedances are important, and their presence may not affect the simultaneity of the balances. One cause may be mutual inductance between the different arms, which for obvious reasons should be reduced to the lowest possible value consistent with keeping capacitance between leads within reasonable limits. There is also the case of cross-capacitances between exposed points of the system which are at different potentials. Important examples are the capacitances from the insulated terminals of the condensers K in the capacitance-arm to the outer cases of the condensers C, assuming them for the moment to be unscreened. These cross-capacitances, although minute in value, are thrown across the whole resistance arm, whereas the power-factor-measuring condensers, in precision measurements on high-grade air condensers at frequencies of the order of 1 million cycles per sec., are shunted across only a small fraction of the arm. This fraction is normally $10 : 100\sqrt{10}$, so that, in terms of the readings of the measuring condenser, the cross-capacitance assumes proportions which are increased a thousandfold. In so far as the cross-capacitance is a function of the disposition of the condensers under test, it is obvious that it can introduce serious discrepancies in precision measurements. It will be understood that as long as the high-potential points of the capacitance-arms have to be made easily accessible and are left exposed, the only course open to the operator is completely to screen other bridge arms.

(5) BRIDGE OPERATIONS.

The significance of the main and the Wagner balances will now be discussed in terms of the fundamental bridge equations, followed by the more practical problem of their convergence towards the final condition of simultaneous balances.

(a) *The Main Balance and the Wagner Balance.*

It will be clear from what has gone before that the process of arriving at the final balance of the main bridge consists of bringing first one and then a second detector point, alternately, to the same potential as a third. Control over these operations by the aid of the headphones is exercised by transferring the grid of the high-frequency valve from the one detector point to the other. The adjustments, when the amplifier is connected across the main bridge, are made upon the condensers K and C until silence is obtained. In fact, with the use of a heterodyne beat note, the silence is considerably freer from residual tones due to harmonics than with direct telephone detection at low frequencies. The grid is then transferred to the earthed point and adjustments are made upon the variable resistance R_w on the right, and the variable air condenser C_w, until silence is restored. On connecting the grid to the main

bridge, silence will not in general be maintained. Silence is obtained for both positions of the switch by successive approximations. It is as well to realize that this does not of necessity imply a rigorous state of simultaneity of the bridge balances. If a parasitic voltage v_b is present in the detector lead system when the amplifier is connected to the main bridge, and v_w when across the Wagner bridge, it is obvious that an out-of-balance of $-v_b$ across the main bridge and $-v_w$ across the Wagner bridge will survive when contact with the grid of the amplifier is broken. Other conditions remaining unaltered, the potentials of the three detector points, instead of being equal before and after the amplifier is disconnected from them, are

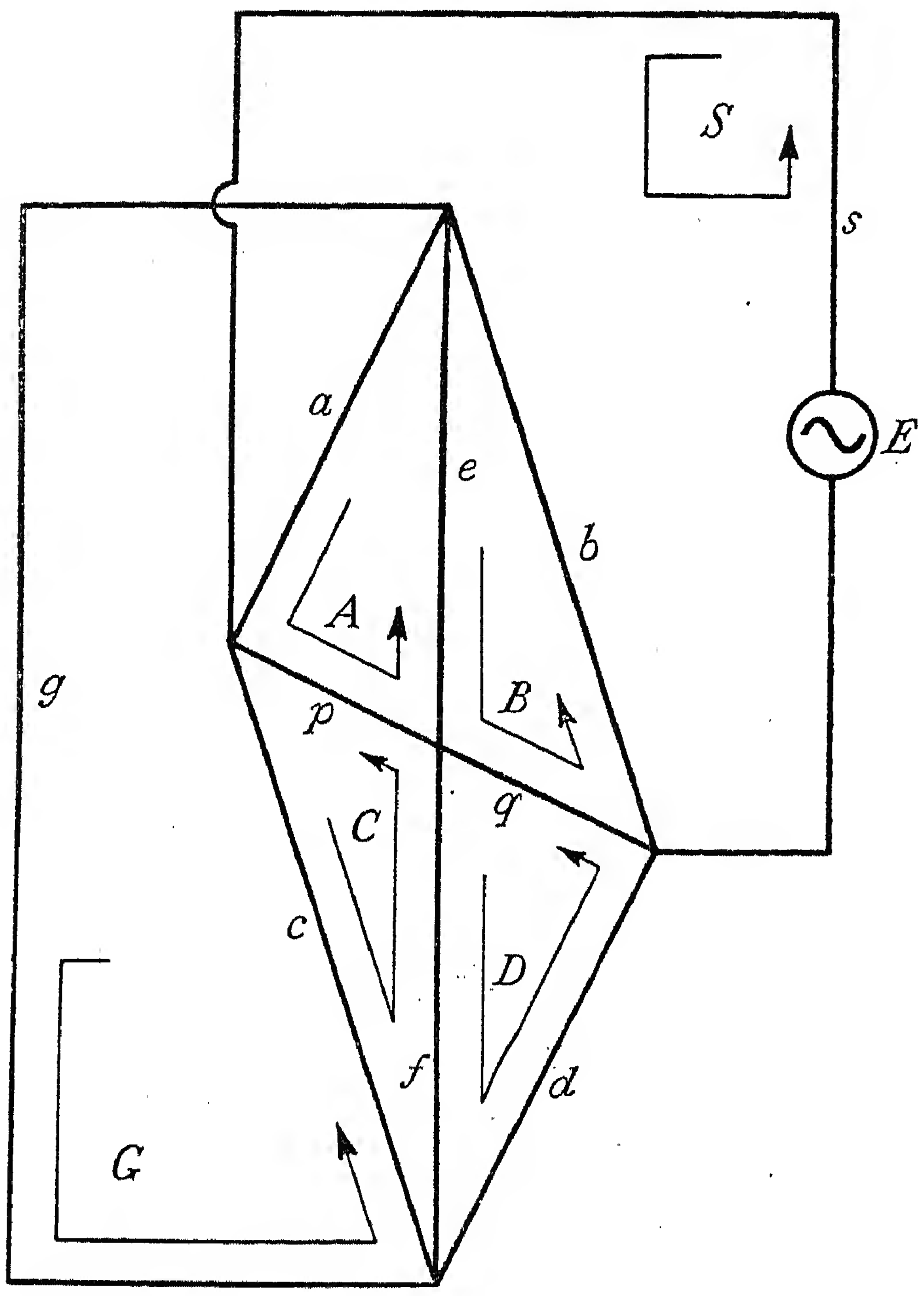

FIG. 4.—General bridge network.

respectively $v_s = 0$; $v_r = \pm(v_w - v_b)$; and $v_k = \pm v_b$. Such steps as were outlined in the preceding Section must be taken to discriminate between a true equality of potential among the detector points and a contingency of the kind suggested above.

A complete solution of the bridge equations will be found in Appendix II for a four-armed Wheatstone network in which account is taken of the impedances joining any pair of corners. The impedances of the main bridge arms are a, b, c, and d (see Fig. 4). The earth impedances corresponding to the two Wagner arms are p and q. The earth impedances from the detector points are e and f, whereas g represents the impedance across the main bridge.

The condition for a balance across the main bridge is given by the equation

$$(bc - ad)[ef(p + q) + pq(e + f)] + abf(cq - dp) + cde(bp - aq) = 0$$

The condition for a balance across the Wagner bridge is given by the equation

$$(bp - aq)[cd(f + g) + fg(c + d)] + gpq(bc - ad) - abf(cq - dp) = 0$$

During the initial stages, the adjustments necessary for obtaining a balance merely produce the indiscriminate vanishing of one or other of these expressions, as the case may be. In the course of the process the operation may be assumed to become more and more selective, with the result that in the final resort all three constituent terms vanish independently and both expressions become equal to zero in virtue of the satisfying of the relations

$$\frac{a}{b} = \frac{c}{d} = \frac{p}{q}$$

Nothing short of this relation among the main impedances can produce a unique balance of the main bridge. It is to be observed that although the partial balances are controlled by the values of all the earth impedances, and the rate of progress of the operations is affected by them, the final main balance is entirely independent of all the earth impedances, being given by the relation

$$bc - ad = 0$$

(b) *The Convergence of the Bridge Balances.*

The rate of progress from an arbitrary initial condition of affairs in the bridge network to the final state of simultaneity of balance can be judged by the number of alternations that are found necessary before the desired state is attained. The phenomenon can be described as the convergence of the bridge balances. Rapid convergency is a desirable property in any bridge system. Foremost among the retarding influences are parasitic voltages induced in the detector circuits. If these exist the three individual terms in the bridge equations never vanish together at a balance. In an early form of the bridge assembly this factor predominated and produced very marked results. If a series of readings were taken on the power-factor-measuring condenser C, or the Wagner resistance R_w, during the converging operations, and the differences of each value from the value satisfying the final balance were deduced and treated as a sequence of displacements of the vector under observation from the balance condition, they were found to correspond to a *constant* decrement. This decrement could be either greater, equal to, or less than unity, according to the value of the impedance of the bridge arms. The progress of the bridge adjustments would therefore be correspondingly divergent, stationary (as between two set readings), or convergent. The divergence and the convergence in general were both "oscillatory," alternate adjustments of the same vector being alternately above and below the final setting, but in cases of extremely rapid convergence the displacements were all unilateral and the process could almost be described as "dead-beat." The steps taken to eliminate mutual induction into the detector circuit considerably improved the convergence of the balances. As the bridge is constituted at present, certain small retarding influences still remain, but although they

exert a discernible effect collectively, the effect of each individually is minute and difficult to identify. Recourse has therefore to be had to an artifice for controlling and facilitating the progress of convergence.

In the course of an investigation into the exactness of the preservation of simultaneity of balance, it was observed that the connection of a condenser between the detector points r and s rendered the process more divergent, whereas a resistance rendered it more convergent. The rate of convergence thus appears to be connected with the earth impedances associated with the detector system. Following up this clue, a resistance was introduced across the studs in the amplifier box (Fig. 2) and was adjusted to give a convenient rate of convergence of the bridge balances for the range of arm-impedances with which the bridge was expected to cope. The resistance value adopted was 50 ohms. The earth impedances e and f therefore consist of the earth capacitance of the amplifier batteries and of a 50-ohm resistance respectively.

The following observation is adduced in support of the validity of the introduction of the resistance. The switch, which selects the stud to which the grid is to be connected, is sufficiently wide to span the distance separating the two studs when it is half-way across from one to the other. At that instant the two studs are connected through a negligibly small resistance. Before the true state of balance is attained, the amplifier gives out notes of different intensities corresponding to the three positions of the switch. When, however, silence prevails on both studs, it is undisturbed in the intermediate position. It therefore follows that the final balance is independent of the order of the impedance connecting the grid to earth. The fundamental conditions in the development of the bridge equations must, therefore, be satisfactorily fulfilled.

The following example, taken during a comparison of precision condensers, is given to illustrate the type of convergence which is met with at 1 million cycles per sec. under the typical conditions specified in Table 3.

TABLE 3.

Capacitance arms, 200 $\mu\mu$F; resistance arms, 316·2 ohms; condenser sections, 10 ohms; Wagner resistances, 2 000 ohms.

Main network			Wagner network	
K	C	$\Delta\phi$	C_w	R_w
$\mu\mu$F	$\mu\mu$F		Setting	
205·2	160	− 0·0004	3°	2 081·5
203·7	435	− 0·00005	5·8°	1 986·$_6$
204·$_2$	513	+ 0·00005	4·8°	2 012·4
204·0	462	− 0·00002	4·75°	2 006·0
204·0	477	+ 0·00000$_4$	4·75°	2 007·6
204·0	475	0·00000$_0$	4·75°	2 007·$_6$

(6) APPLICATIONS OF THE BRIDGE.

A wide variety of measurements may be made by means of the bridge. In cases in which the component to be measured has a large impedance it is connected in parallel with one of the capacitance arms of the network containing a standard variable air condenser K. When, however, the unknown impedance has a low value, it is connected in series with the condenser. In both types of test the method of measurement consists of observations of the change in the standard variable condenser K, and of the difference in setting of one of the condensers C, shunting a suitable fraction of the resistance arm. From these two differences the two components of the impedance may be calculated.

Measurements falling into the first class are:—

(i) Capacitance and effective resistance of condensers.
(ii) Permittivity and power factor of dielectrics.
(iii) Capacitances and their power factors between pairs of electrodes of thermionic valves.
(iv) Resistance, reactance, and impedance of chokes and high resistances.
(v) Effective inductance, self-capacitance, and resistance of large inductance coils.

Measurements in the second class, i.e. low impedances, include the effective inductance and the effective resistance of small inductance coils and conductors.

A coil of almost any value can be tested by either of the two methods at most frequencies by a suitable choice of the capacitance of the condenser K with which it is combined.

The study of individual applications of the bridge to such types of measurements is beyond the scope of the present paper. It is considered that the suitability of bridge methods up to frequencies as high as 1 million cycles per sec. has been proved, and that a Schering bridge constructed on the lines described can measure, to an accuracy of 1 per cent, power factors lying between the limits of 0·001 and 0·1. Comparison measurements on precision air condensers can be relied upon to give power-factor differences to 0·00001 up to 1 million cycles per sec.

(7) ACKNOWLEDGMENTS.

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The original scheme was conceived by the late Dr. Dye, who was assisted by Mr. E. C. Cork, B.Sc., especially in the design and construction of the compact high-frequency source and the detector-amplifier. The co-author (Mr. T. Iorwerth Jones), who carried out the later investigations and modifications of the apparatus, wishes to acknowledge his indebtedness to Dr. L. Hartshorn and Dr. R. L. Smith-Rose for valuable advice in the course of the preparation of the paper.

REFERENCES.

(1) C. ENGLUND: "Note on Radio-frequency Measurements," *Proceedings of the Institute of Radio Engineers*, 1920, vol. 8, p. 326.

(2) M. D. HART: "A Bridge for Determining Dielectric Losses at Wireless Frequencies," *Journal I.E.E.*, 1923, vol. 61, p. 697.

(3) J. A. STRATTON: "A High-frequency Bridge," *Journal of the Optical Society of America*, 1926, vol. 13, p. 471.

(4) W. J. SHACKLETON: "A Shielded Bridge for Inductive Impedance Measurements at Speech and Carrier Frequencies," *Bell System Technical Journal*, 1927, vol. 6, p. 142.

(5) J. G. FERGUSON: "Shielding in H.F. Measurements," *ibid.*, 1929, vol. 8, p. 560.

(6) B. W. BARTLETT: "A Shielded Bridge for the Measurement of Inductance in terms of Resistance and Capacity," *Journal of the Optical Society of America*, 1928, vol. 16, p. 409.

(7) C. P. BONER: "The Measurement of Capacitance and Inductance in terms of Frequency at Radio Frequencies," *Review of Scientific Instruments*, 1930, vol. 1, p. 243.

(8) K. KÜPFMÜLLER: "A High-frequency Wheatstone Bridge," *Elektrische Nachrichten-Technik*, 1925, vol. 2, p. 263.

(9) K. SCHLESINGER: "High-frequency Measuring Apparatus for determining Dielectric Constants," *Elektrotechnische Zeitschrift*, 1931, vol. 52, p. 533.

(10) B. HAGUE: "A.C. Bridge Methods" (Pitman's).

APPENDIX I.

DETAILS OF THE TOROIDAL INDUCTANCES.

The details which follow refer more particularly to the toroidal screened coils which were constructed for use in connection with the screened high-frequency source. The amplifier coils were similar but they contained only one winding, the middle point of which was brought out.

A keramot former is used of external diameter 9 cm, internal diameter 3 cm, and height 4·5 cm. It consists of two cheeks 1 cm (approx.) thick, held together by four keramot pins 1·25 cm (approx.) in diameter. On this core the anode winding is wound progressively round the circumference, in more layers than one if necessary, from the starting point back to the same point, ample precautions being taken, by wrapping silk tape over the first few turns, to preserve a high degree of insulation between the two abutting ends of the winding. This winding is then covered by a layer of silk tape. The grid winding is then wound progressively upon it and is distributed uniformly around the circumference in order to preserve to the full the close character of the field associated with the toroidal form. At this stage more insulating material is wrapped over the grid winding. It is intended not merely for insulating purposes but for maintaining a suitable distance between the winding and the copper screen which surrounds it. Turns of silk tubing 1 cm apart on the outer rim possess the advantage that no more dielectric than is really necessary is introduced into the air space.

The screen is made up conveniently from two lids a, b, carrying two brass tubes c, d (Fig. 3*a*), which do not meet when inserted into the coil. A sheet of very thin copper is then soldered on to the inner sides of the lids to complete the metal box.

A layer of silk tape is wound on the copper screen, and the output winding is then disposed uniformly around its circumference. A lead is brought out from the inner screen to be soldered to the more robust copper box which is constructed to take the completed coil. The six ends of the three windings are suitably insulated and brought out to six split-pins mounted on an ebonite disc, which is attached to the lower face of the screen box and is held in place by a central ebonite bolt screwed into the knob on the opposite face. The coil, complete with screen, is shown in Fig 3(*b*). The details of the number of turns composing the windings of the six coils are given in Table 4.

TABLE 4.

Oscillator coil	Frequency range	Number of anode turns	Number of grid turns	Number of output turns
	kilocycles/sec.			
A	400–1 200	60	30	10
B	200–500	120	60	20
C	100–250	240	120	40
D	50–120	480	240	80
E	24–50	960	480	300
F	12–25	2 000	1 000	800

To simplify the winding of coil F, the former was constructed in two halves, and pins were inserted at intervals to subdivide the winding into smaller sections around the circumference. Each half was wound apart, leaving but two small incomplete sections on either side of the joints, the turns of which had to be threaded through the centre.

APPENDIX II.

DEVELOPMENT OF THE SOLUTION OF THE GENERALIZED BRIDGE EQUATIONS.

A Wheatstone bridge network is represented in Fig. 4, where a, b, c, and d are impedances joining adjacent corners of the network (i.e. they are the four main arms) and p, q, e, f, and g are impedances joining opposite corners directly or to a fifth point corresponding in practice to the earth. The impedances p and q would correspond to the two auxiliary arms forming the Wagner earthing system, when the balances were taken across any pair of the impedances e, f, and g. The impedances e and f would correspond to the two arms of the Wagner earthing system in the conjugate system obtained by the interchange of source and detector. E is the e.m.f. applied to the system, while s represents the impedance of the source.

Applying Kirchhoff's equations, we obtain

$$S(s+p+q)+(A-C)p+(B-D)q=E \quad . \quad (5)$$
$$A(a+p+e)+(S-C)p+(G-B)e=0 \quad . \quad (6)$$
$$B(b+e+q)-(A+G)e+(S-D)q=0 \quad . \quad (7)$$
$$C(c+f+p)-(S+A)p+(G-D)f=0 \quad . \quad (8)$$
$$D(d+q+f)-(S+B)q+(G+C)f=0 \quad . \quad (9)$$
$$G(g+e+f)+(A-B)e+(C-D)f=0 \quad . \quad (10)$$

The condition for the main bridge balance is that there should be no current in g; or $G=0$ (across g).

For the Wagner-bridge balance the condition is that there should be no current in e or in f, which reduces to $A + B - G = 0$ (across e) or $C + D - G = 0$ (across f).

When the current terms have been eliminated from the six equations set out above, the condition $G = 0$ can be expressed in the two alternative forms

$$(bc - ad)\left[ef(p + q) + pq(e + f)\right] + abf(cq - dp) + cde(bp - aq) = 0$$

$$(bc - ad)\left[ef(p + q) + pq(e + f)\right] + acq(bf - de) + bdp(ce - af) = 0$$

which imply that the unique balance, obtained when all three terms vanish together, can be realized by adjusting *either* the impedances to earth, p and q, which form the Wagner earthing system, *or* the impedances to earth, e and f, from the detector points, which would form the Wagner earthing system of the conjugate bridge. In practice, resort has to be had to the former alternative, in view of the guidance which the Wagner-bridge balance affords. Nevertheless, the presence of the earth impedances at the detector points in the expression for the ordinary balance, as opposed to the simultaneous balance, supports the assumption that they can materially influence the rate of progress towards the attainment of a true state of simultaneity of balance in the network.

The equations which have to be satisfied in the two Wagner-bridge balances are:—

Case (i). Across e.

$$(bp - aq)\left[cd(f + g) + fg(c + d)\right] + gpq(bc - ad) - abf(cq - dp) = 0$$

Case (ii). Across f.

$$(cq - dp)\left[ab(e + g) + eg(a + b)\right] + gpq(bc - ad) - cde(bp - aq) = 0$$

Comparison with the equation for the main balance brings out very clearly the expected result that the only unique balance is the simultaneous balance, which requires

$$a/b = c/d = p/q, \text{ or } e/f$$

PROCEEDINGS OF THE INSTITUTION.

838TH ORDINARY MEETING, 20TH OCTOBER, 1932.

Mr. J. M. Donaldson, M.C., Past-President, took the chair at 6 p.m.

The minutes of the Extra Ordinary Meeting (Varley Centenary) and of the Annual General Meeting held on the 5th May, 1932, were taken as read and were confirmed and signed.

A list of candidates for election and transfer, approved by the Council for ballot, was taken as read and was ordered to be suspended in the Hall.

The Chairman announced that, during the period April to September, 801 donations and subscriptions to the Benevolent Fund had been received, amounting to £533. A vote of thanks was accorded to the donors.

The Premiums (see vol. 71, pages 143 and 402) awarded for papers read or published during the past session were presented by the Chairman to such of the recipients as were able to be present.

Mr. Donaldson then vacated the chair, which was taken by **Professor E. W. Marchant, D.Sc.,** President, amid applause.

Col. Sir Thomas F. Purves: The pleasure of meeting our new President to-night is naturally tempered with a kind of farewell feeling for his immediate predecessor, and on that account I have the honour to move this resolution: " That the best thanks of the Institution be accorded to Mr. J. M. Donaldson for the very able manner in which he has filled the office of President during the past year." In Mr. Donaldson the Institution has had a strong President. His decision of character, his clear judgment, and his gifts of ready and cogent speech, have all been placed unreservedly at the service of the Institution, and have served it well. If I were asked to epitomize my impressions of Mr. Donaldson I think I might do it in four words: " equal to the occasion." He has certainly shown himself equal to all sorts and kinds of occasions during the past year. He has well and truly steered the ship on a straight course, and he has always done it most gracefully and most pleasantly. I am sure that his year of office has added to the influence and to the authority of the Institution. He has now earned the permanent right to sit, like Nestor, at the Council's board, where we know that he will continue the hearty co-operation in the Institution's activities that he has afforded, so fully and so freely, in the past.

Mr. J. M. Kennedy: I endorse every word that Sir Thomas Purves has said with reference to our retiring President. We know how active he has been throughout the year in looking after the interests of the Institution, and his activity has been very forcibly borne in on me, because, as a Vice-President, I have been called on so little to act on his behalf. I have very great pleasure in seconding the resolution.

The resolution was then put to the meeting by the President, and was carried with acclamation.

Mr. J. M. Donaldson: I should like to thank Sir Thomas Purves and Mr. Kennedy for the way in which they have proposed this resolution, and you for the way in which you have received it. I can say only this, that I have done my best, and nobody can do more. It is idle to say that one does not take a very great pride in being the head of an Institution such as this. I have appreciated the warm-hearted support which is given in

full measure to the President for the time being. It makes his task very easy. The loyalty of the members of the Council is also a very great help, nor must one forget that the President's task is made extremely simple by the assistance which is given him by the permanent staff.

The President then delivered his Inaugural Address (see page 1).

Mr. C. C. Paterson: We have listened this evening to an Address which will take a worthy place amongst the long series of addresses delivered from the presidential chair. The day is past when the presidential address was merely a review of electrical progress. Prof. Marchant has given us a view of electrical engineers and of electrical engineering as seen from the vantage ground of the university. I suppose the man who said that education is what is left when we have forgotten everything we were ever taught was only expressing differently what Prof. Marchant said in his Address, that the development of initiative and thinking power is the principal end to which the scientific training of an engineer should be directed. The President has emphasized the need for a broad franchise or qualification for admission to the Institution, and has pointed out that we have now opened our doors to enable physicists to become members of the Institution. Certain it is that the old idea of the electrical engineer as merely a man of generators and of transformers and switchgear is rapidly passing away. It seems to me that the new generation of electrical engineers are physicists by instinct and engineers by contamination; and this idea, I am sure, has led the President to his timely reminder of the debt to physics which the Institution recognized it owed, and which for some 30 years it has been trying to pay back, by its maintenance of the Physics Section of *Science Abstracts*. It is not for me to enlarge upon the many fascinating topics on which the President has touched so eloquently, but I will merely thank him for his Address in the words of the time-honoured resolution of this Institution, namely: "That the best thanks of the Institution be accorded to Prof. Marchant for his interesting and instructive Presidential Address, and that with his permission the Address be printed in the *Journal* of the Institution."

Dr. W. H. Eccles: I rise to second this resolution with special gratification, because it shows me that the Institution is adhering to its old tradition of keeping in close touch with the academic world. If one looks through the list of Past-Presidents for 50 years, one finds that every few years there appears the name of a distinguished professor, an educationist, who has thus been elevated to the position of highest influence that the Institution can give. One advantage of this, it seems to me, is similar to that obtained by the farmer from the process called the rotation of crops. It gives greater fertility to the Institution, and stronger growth, and maintains contact with the growing edge of electrical science in all directions of its advance. With regard to the Address itself, I should particularly like to thank the President for dwelling strongly on two things: one the research side, and the other the educational side of electrical engineering. With regard to the research side, I think that the Institution has never believed in the old saying that an ounce of practice is worth a ton of theory, but rather, as the President has emphasized, we have always held the belief that an ounce of theory may some day create tons of practice. As to the educational side of the Address, we have been given the fruit of 30 years of experience in teaching and the organization of university courses, in examination work, and in the award of scholarships. We shall look forward to reading the Address in full in the *Journal*. I have great pleasure in seconding the vote of thanks.

The vote of thanks was then carried with acclamation.

After the President had briefly replied the meeting terminated at 7.20 p.m.

839TH ORDINARY MEETING, 3RD NOVEMBER, 1932.

Prof. E. W. Marchant, D.Sc., President, took the chair at 6 p.m.

The minutes of the Ordinary Meeting held on the 20th October, 1932, were taken as read and were confirmed and signed.

Messrs. W. G. Bass and D. J. Bolton were appointed scrutineers of the ballot for the election and transfer of members and, at the end of the meeting, it was reported that the members whose names appeared on the lists (see page 88) had been duly elected and transferred.

The President announced that, during the month of October, 51 donations and subscriptions to the Benevolent Fund had been received, amounting to £36. A vote of thanks was accorded to the donors.

A paper by Messrs. A. B. Read and J. W. T. Walsh, M.A., D.Sc., Member, entitled "Electric Lighting of Buildings" (see page 93), was read and discussed.

The meeting terminated at 7.42 p.m. with a vote of thanks to the authors, which was moved by the President and carried with acclamation.

INSTITUTION NOTES.

Honorary Member.

At the Ordinary Meeting of the Institution held on the 19th January, 1933, the President announced that the Council had that day elected Mr. Llewellyn B. Atkinson, Past President, to be an Honorary Member of the Institution.

Communications from Overseas Members.

Overseas members are especially invited to submit for publication in the *Journal* written communications on papers read before the Institution or published in the *Journal* without being read. Such communications should not exceed 400 words in length. The contributor's country of residence will be indicated in the *Journal*. In this connection a number of advance copies of all papers read before the Institution are sent to each Local Hon. Secretary abroad to enable him to supply copies to members likely to be in a position to submit communications.

National Certificates and Diplomas in Electrical Engineering (England and Wales).

The undermentioned colleges have been approved under the scheme drawn up by the Board of Education and the Institution.

Approved for Ordinary Grade Certificates (Senior Part-time Course).

Stretford, Old Trafford Technical Evening Institute.
Dursley Evening Institute.
York Technical Evening Institute.

Approved for Higher Grade Diplomas (Advanced Full-time Course).

Sunderland Technical College.

Graduateship Examination Results: November, 1932.

*Passed.**

Abideen, S. (London).
Aubin, R. E. L. (London).
Bedingham, A. S. (Nuneaton).
Bevan, E. L. (London).
Brierley, F. (Croydon).
Brown, H. R. (Cambridge).
Dempsey, J. (Exeter).
Evans, F. W. (Bath).
Everitt, G. N. (Sheffield).
Foster, R. S. (Croydon).
Gambold, T. H. (Swansea).
Gatehouse, H. W. C. (London).
Gerard, W. B. (Leith).
Harthan, E. P. (Manchester).
Hayes, E. W. (Newport, Mon.).
Hort, E. P. (London).
Huff, S. H. (Bath).
Jarvis, W. H. (Widnes).
Monckton, J. (Bristol).
Nicol, A. E. (Walton-on-Thames).
Nottage, W. G. (Bromley).
Otty, E. H. (Aberdeen).
Powell, W. N. (Hastings).

* This list also includes candidates who are exempt from, or who have previously passed, a part of the Examination and have now passed in the remaining subjects.

Passed—continued.

Price, T. W. (Cossall).
Pyman, E. J. R. (Lowestoft).
Rees, T. J. (Cowbridge).
Scholefield, S. (Stone).
Slee, W. J. G. (Lancaster).
Talbot, F. G. (Willesden).
Teather, R. H. (Belfast).
Thomas, A.R. (Ton Pentre).
Thomas, W. J. T. (Southampton).
Thompson, E. H. (Rugby).
Waite, D. (Belfast).
Williams, H. M. (Oswestry).
Williams, R. J. (Weymouth).

Passed Part I only.

Butt, W. G. (London).
Kinkead, R. L. (Lurgan).
Miller, W. L. E. (Westcliff-on-Sea).
Murti, P. N. (Wembley Park).
Sutherland, J. H. (Croydon).
Tatum, R. B. (Frinton-on-Sea).
Thomas, C. C. (Halifax).
Wade, A. M. (Birmingham).
Walker, A. W. P. (Edinburgh).

Passed Part II only.

Baskerville, J. J. P. (Limerick).
Brigstocke, W. G. P. (Ryde).
Garside, F. (Basingstoke).
Gay, H. (Pontnewydd).
Gossling, F. G. (Rugby).
Harrison, H. (Bolton).
Kendall, P. J. O. (Needingworth).
Mather, S. L. (East Kirkby).
Miller, A. A. (Glasgow).
Price, S. (Rugby).
Richards, J. G. (Newport, Mon.).
Richardson, R. B. (Ramsgate).
Sen, P. K. (Newcastle-on-Tyne).
Smith, L. (Newcastle-on-Tyne).
Stockwell, T. (Waterfoot).
Trenhaile, C. (Abertillery).
Tucker, J. H. L. (Wallsend).
Wilson, A. (Sunderland).

Further results, relating to candidates who sat for the Examination abroad, will be published later.

Proceedings of the Wireless Section.

101st Meeting of the Wireless Section, 2nd November, 1932.

Prof. E. W. Marchant, D.Sc., President, took the chair at 6 p.m.

The minutes of the meeting held on the 25th May, 1932, were taken as read and were confirmed and signed.

A vote of thanks to Col. A. S. Angwin, D.S.O., M.C., B.Sc.(Eng.), for his services as Chairman of the Section during the session 1931–32, proposed by Dr. E. Mallett, and seconded by Mr. T. Wadsworth, was carried with acclamation.

Mr. L. B. Turner, M.A., Chairman of the Section, then delivered his Inaugural Address (see page 10).

A vote of thanks to Mr. Turner for his Address was proposed by the President and, after being put to the meeting, was carried with acclamation.

The meeting terminated at 7.20 p.m.

102nd Meeting of the Wireless Section, 7th December, 1932.

Mr. L. B. Turner, M.A., Chairman of the Section, took the chair at 6 p.m.

The minutes of the meeting held on the 2nd November, 1932, were taken as read and were confirmed and signed.

A paper by Prof. J. Hollingworth, M.A., D.Sc.(Eng.), entitled "Some Characteristics of Short-Wave Propagation," was read and discussed.

The meeting terminated at 7.45 p.m. with a vote of thanks to the author, which was moved by the Chairman and carried with acclamation.

Proceedings of the Meter and Instrument Section.

30th Meeting of the Meter and Instrument Section, 4th November, 1932.

Prof. E. W. Marchant, D.Sc., President, took the chair at 7 p.m.

The minutes of the meeting held on the 29th April, 1932, were taken as read and were confirmed and signed.

A vote of thanks to Mr. F. C. Knowles for his services as Chairman during the session 1931–32, proposed by Mr. E. E. Sharp and seconded by Mr. Wilfred Holmes, was carried with acclamation.

The President then vacated the chair, which was taken by Mr. R. S. J. Spilsbury, Chairman of the Section, who delivered his Inaugural Address (see page 30).

A vote of thanks to Mr. Spilsbury for his Address, proposed by the President and seconded by Dr. C. V. Drysdale, C.B., O.B.E., was carried with acclamation.

The Chairman reported the award of Premiums for 1931–32 for Meter and Instrument Section papers (see vol. 71, page 144). The meeting terminated at 8.30 p.m.

31st Meeting of the Meter and Instrument Section, 2nd December, 1932.

Mr. R. S. J. Spilsbury, Chairman of the Section, took the chair at 7 p.m.

The minutes of the meeting held on the 4th November, 1932, were taken as read and were confirmed and signed.

A paper by Messrs. F. P. Burch, B.A., and R. V. Whelpton, M.Sc., entitled "The Technique of the High-Speed Cathode-Ray Oscillograph" (see vol. 71, page 380), was read and discussed.

The meeting terminated at 9.35 p.m. with a vote of thanks to the authors, which was moved by the Chairman and carried with acclamation.

Elections and Transfers of Members.

At the Ordinary Meeting held on the 19th January, 1933, the following elections and transfers were effected:—

Elections.

Associate Members.

Adams, Basil Norwood, B.Sc.(Eng.).
Addison, Edward Barker, M.A., Flight-Lieut., R.A.F.
Baker, Thomas William.
Bishop, John.
Brown, Arthur.
Bugden, Alfred George, B.Sc.(Eng.).
Burch, Francis Parry, B.A.
Burman, Harold Percy.

Associate Members—continued.

Chamberlain, John Campbell S., Lieut.-Commdr., R.N.
Cooper, Arthur.
Cooper, Cecil Redvers, B.Sc.
Costelloe, Walter Henry G., Capt., R.E.
Earls, Arnold, B.Sc.
Eunson, David Moncrieff.
Falshaw, Reginald.
Fisher, Ben James, Lieut.-Commdr., R.N.
Freeman, Henry.
Gray, Herbert Charles.
Griffiths, Clyde James, B.E.E.
Harper, Frederic Arthur, M.A.
Harris, Gavin Mure, B.A.
Mellor, Alfred Henry.
Millar, Ivan Paul.
Oliver, Cuthbert Jack, B.Sc.
O'Reilly, Christopher, B.E.
Powell, Henry Townsend, Lieut., R.N.
Raven, Thomas Frederick.
Ryan, Richard John H., Lieut., R.N.
Scobie, James, B.Sc.
Smart, Geoffrey William, B.Sc.
Smith, Harvey Allan.
Stevenson, George Lowther, B.A.
Sutton, George William, B.Sc., Ph.D.
Taplin, Keith William, B.E.
Thwaites, Joseph Edward.
Tillotson, Sam.
White, James Albert.
White, William Ronald.
Wright, Esmond Philip G.
Wykes, Jack Pennington.

Associates.

Alford, William Kenneth.
Dickinson, William, B.Sc. (Eng.).
Hall, Leonard George.
Harries, John Vaughan.
Harvey, Albert Henry.
Hill, David Smith.
Hill, Henry Herbert.
Hodson, John Sholl.
Powell, Arnold.
Roberts, George William P., M.B.E., B.Sc.(Eng.).
Russell, Douglas Arthur.
Stratton, Harry Thomas.
Tilstone, George.
Van Tilburg, Johan Adrian.
Vaughan, James Marshall.
White, Henry William.
Willsmer, Gifford Joseph.

Graduates.

Adamson, Walter.
Agar, George Lawrence, B.Sc.
Atkinson, William Ranson.
Baker, Cyril Arthur.
Bapat, Mahadev Nilkanth.
Barber, Douglas Murray.
Batchelor, Ernest Lawrence.
Bell, Joseph Cecil G.
Bennett, Samuel John, B.Sc.Tech.
Bevan, Kenneth John.
Bhaumik, Amulya Kumar, B.Sc.(Eng.).
Bilimoria, Phiroze Dadyba, B.Sc.(Eng.).
Bishop, Walter Martin, B.Sc.(Eng.).
Borissow, Bernard Gamon, B.Sc.(Eng.).
Bowden, Harold George.
Bradshaw, Eric, M.Sc.Tech.
Brooker, Kenneth Richard.
Brown, Hugh Boyd, B.Sc. (Eng.).
Burgess, Arthur Helme.
Butcher, Derek St. Aubyn.
Clay, Alfred John.
Cole, Maxwell Harry.
Collett, Eric John C.
Coop, Kenneth Charles, B.Eng.
Darlow, Bertram John, B.A.
D'Lima, Marcus Joseph A.
Dobbie, Leonard Graham, B.E.
Doshi, Jagjivandas Hiralal.
Eales, Archibald John, B.Sc.(Eng.).
Ferry, Henry, B.Sc.(Eng.).
Fielding, Jack Gomersall.
Forrest, John Samuel, M.A., B.Sc.
Fowler, Leslie Arthur.
France, James Eric.
Francis, Ernest George.
Geoghegan, Robert Sherbotoff, B.A.
Golding, Royden Charles.
Govindakrishnayya, Pasupuleti, M.E.

Graduates—continued.

Griffiths, John Horace.
Gupta, Sudarshan Lal.
Gurtu, Ram Krishna, B.Sc.
Harris, Richard Haymen.
Hayderi, Nazim.
Hayes, John Barry, B.Sc. (Eng.).
Herschdoerfer, Joseph, Dr. Ing.
Hiles, Leslie Fitzallen.
Holmes, Cyril Thomas.
Hounsfield, Robert Brailsford, B.A.
Hughes, Leslie Laurence.
Hyde, Harry.
Hyland, William, B.Sc.Tech.
Jinks, Cyril Ernest, B.Sc. (Eng.).
Jones, Emlyn, B.Sc.
Kantayya, Anandarao Ganugapati, D.E.E.
Kennan, Lorcan William.
Lanchester, Ronald Ainslie.
Laycock, Gerald Simpson, B.Sc.
Ledger, Hugh Hallam.
Leeks, Clifford Canute.
McGuffin, Harry, B.Sc.
McIlwrick, Gilbert Menzies, B.Sc.
McKearney, Philip.
Mackie, Andrew Douglas.
Marples, Elwyn Ivo B.
Marsden, Roderick Hudson, B.Sc.
Marsden, Wilfred Kenneth.
Marshall, David Samuel, B.Sc.
Milne, Grant Raglan, B.Sc.
Mitchell, John Harwood G., B.A.
Mitchell, Thomas Mordey.
Morris, Peter Maurice G., B.Sc.
Nicolaisen, Rentz Furster.
Nicolson, Torquil, B.Sc.
Noble, Ernest Mark, B.Sc. (Eng.).
Nonhebel, Kenneth, B.Sc. (Eng.).
Northcott, William James O.
Obouhoff, Paul Alexander.
Ockwell, Ernest Henry.
Palmer, Stanley.
Peterson, George Rainy.
Plank, Charles Stephen, M.Sc.
Plummer, Cyril Charles, B.Sc.
Price, Lionel James.
Rao, B. V. R. Suryanarayana, B.E.
Rawding, Ronald William.
Rawnsley, John Ensor.
Raymond, George Edward R.
Rhodes, Henry Neville.
Robson, Walter Blakey.
Rolls, Thomas Burnand.
Sarathy, Nemam E. Partha.
Sharp, Andrew.
Simpson, Charles.
Simpson, George Linklater, B.Sc.
Sinnathamby, Sinnathamby P.
Stockings, Thomas.
Thorley, Thomas.
Thorp, Charles Sidney.
Throsby, Frank Stanley.
Thurner, Walter Maurice F., B.A.
Tyler, Bernard.
Vulliamy, Adrian Theodore, B.A.
Wallis, George Ernest.
Wallwork, William.
Watteeu, Guy James de L., B.Sc.
Webb, Keith Stuart, B.A.
Webb, Reginald.
Welch, Douglas Francis, B.A.
Whatman, Amherst Barrow.
Wheat, Robert Henry.
Whiffin, Albert Charles, B.Sc.
White, Arthur Barwood, B.Sc.
Yates, John.

Students.

Ahluwalia, Iqbal Singh.
Aiyar, Subramani Ramaswamy, B.A.
Allen, John Marshall.
Allen, Maurice, B.Eng.
Ansell, Sidney Clifton.
Apte, Ramchandra Yeshwant.
Askham, William Ekin.
Bache, Derick John, B.Sc.
Baker, Howard.
Baker, Thomas Buller.
Balch, Chester Royce.
Barker, Harry Taylor.
Barnes, Eric Robert.

Students—continued.

Barton, Raymond Chetwode.
Bayly, George Dallas.
Best, John Edward.
Bhardwaj, Diwan Chand.
Billington, William Ernest.
Birch, Sidney George.
Bland, Reginald.
Boardman, Brian Reginald L.
Bojesen, Carl Christian.
Bolton, Ronald James.
Bond, William Alfred.
Bone, Francis William.
Bowler, Charles Godfrey M.
Bradley, Joseph Edward.
Bradley, Reginald Gilbert.
Bradley, Thomas.
Bradshaw, Arthur.
Brazel, Lawrence Walton.
Brent, Edwin Ronald S.
Brewster, Harry George.
Brierley, Frank.
Brocklesby, Harry.
Brook, George Henry.
Brookman, Alfred William G.
Brown, Cyril Dykes.
Brown, Henry Robert.
Brown, Ian Spencer H.
Brown, Maurice Crompton, L.
Browne, Frederick Bernard.
Buchan, William Sale.
Buckingham, George Ronald.
Busby, Sidney Donald.
Caldwell, Thomas Hugh Y.
Campe, William Kenneth.
Candy, Bernard Osborne.
Canning, Francis Richard.
Cartwright, Jack.
Cassad, Dhunjisha Pestonji R., B.Sc.
Caswell, Arthur Frederick.
Chadwick, Allen.
Chadwick, Wallace.
Chambers, William.
Channing, William Kentish.
Chapman, George Henry.
Chari, Rajagopaliengar Srinivasa.
Charnley, Christopher Nabb.
Clark, Frank Baldwin.
Clark, Frank Everard T.
Clark, Joseph Kenneth.
Clark, William Busby C.
Clarke, Donald Alexander.
Coley, James Perrin.
Collins, Ivor Leslie.
Coop, Gordon Nimmo.
Cooper, Denis Ralph.
Craggs, William Arnold.
Crawcour, David.
Creswell, Frank Ernest.
Cuthbert, Robert.
Damon, Allan William.
Dantanarayana, James.
Datta, Smriti Ranjan.
Davies, George Richard.
Davies, John William.
Dawson, Alfred Alexander.
Denton, Lawrence.
Dhown, C. L.
Dippy, Robert James.
Dodsworth, Ernest John.
Driver, Rustom Maneckshaw.
Drylie, John James.
Dunn, Geoffrey Selwyn.
Durie, John.
Dwyer, Kenneth McIver.
Eagles, Harry, B.Sc.(Eng.).
Eddy, Otis Franklin.
Egan, Patrick Joseph.
Ellis, Ronald.
Evans, Alwyn.
Evans, Leonard James.
Farmer, Frank Taylor.
Fidlan, Frederick.
Fielden, Cyril Fred R.
Finlay-Dempster, Michael John.
Finucane, Paul Condon.
Firth, John Alfred P.
Fisher, George Albert.
Flaye, Charles Donald.
Fletcher, Roy Carruthers.
Forbes, John Alexander.
Fowlie, William Stephen.
Frank, Walter Reginald B.
Frith, Leslie Shaw.
Gabriel, Ralph Parton.
Gardiner, Terence Edward G.
Ghose, Salil Chandra, B.E.
Gordon, Norman.
Gossling, Felix George.
Graham, Cyril Thomas.
Gray, John.
Greenberg, Issy.
Griffith, Edward Estcourt.
Haigh, Roland William.
Hambleton, Edward Primrose.
Hammond, John Durell Le B.
Harman, Robert Charles.
Harper, Frederick George S.
Hart, Albert Frederick.
Hassan, Mas'Ud.

Students—continued.

Hawkes, Edward George.
Hayes, Alfred.
Haysom, Derek William R.
Heiser, Edward John.
Henderson, Lionel Butler.
Henderson, William Begg.
Heys, Ronald.
Hibbert, William.
Hogermeer, Bertram Hugh W.
Holmes, Sydney Whittaker.
Hope, Charles Peter.
Howard, Alan.
Howard, William Henry.
Hoyle, John.
Hudson, Donald North.
Hughes, Harold Llewellyn.
Hughes, James Robinson.
Hutchison, William Burns, Jnr.
Jackson, Albert Cobley.
Jenkins, Donald Frazer L. W.
Jepson, Albert Edward, Jnr.
Jessop, James Mark.
Johnson, Alan.
Johnson, Benjamin Marrows.
Jones, Allan Newton.
Jones, Clifford.
Kassell, Edward Douglas.
Kelly, Michael.
Kingsnorth, Robert John.
Kinkhead, Robert Louis.
Knox, James.
Lally, Eric James.
Lal-Sarin, Pyare.
Laycock, Dudley.
Leitch, Archibald Kerr.
Leslie, William McFadyen.
Lewis, Kenneth Rupert.
Lieversz, Douglas Winston L.
Lindsay, David Graham.
Line, Alfred Clayton T. D.
Littlejohn, Robert Duncan.
Lloyd, Geoffrey Osborne.
Lochhead, Ian Ferguson.
Locke, Ronald Arthur.
Lockett, Harry.
Lunson, Harold Thomas.
Lynch, Edmund Charles.
Maclachlan, Ian Neil.
Maclachlan, William Stanley H.
McCulloch, Robert Kirkwood.
McInnes, Richard Edward.
Majid, Shaikh, Abdul.
Marr, Robert.
Marrian, Laurence Hamar.
Martin, Frederick Thomas.
Mather, Samuel Leonard.
Mehendale, Anant Ganesh.
Mehta, Framroze Nowroji.
Mel, Cecil Howard J.
Mellor, James Frederick M.
Miller, Albert Arthur.
Mills, Cyril Ernest.
Mohan, A. S.
Moody, Frank Rodney.
Mooraj, Nazerhusein Fazil.
Moore, Charles.
Moore, Frank Bennett.
Moraes, Arthur Denis.
Morcombe, Edgar Herbert.
More, John Clarence.
Narayana Rao, Pollachi Krishna.
Narayana Rao, Tatapudi.
Nayak, Ullal Pundarik.
O'Connell, Eric Francis.
O'Kane, Bernard John.
O'Leary, Bernard George.
Ollerenshaw, Charles.
Ong, Hian Yao.
Ordish, Jack Desmond.
Orford, Gordon.
Otty, Eric Horsfield.
Overton, Frank Gregory.
Pace, Harold Owen.
Padmanabhan, Subrahmanya.
Parker, Joseph Donald.
Parker, William Frederick.
Parr, George Herbert.
Paterson, Joseph Craig, B.Sc.
Pawson, David Francis.
Payne, Geoffrey.
Pearce, Leslie John.
Peet, Richard Henry.
Pereira, Arthur Lynsdale.
Pettifor, Percy Hayward.
Phillips, Charles James.
Phillips, James Huntley, B.Sc.
Piggott, Leslie Sylvester.
Plunkett, William Richard.
Pollock, Thomas.
Presswell, Richard William.
Preston, Henry Somerville.
Preston, John Reford.
Preston, Leslie.
Prout, Leslie Ronald.
Pryor, Charles Geoffrey, B.Sc.
Puri, Piyara Lal.

Students—continued.

Radcliff, Richard Hamilton.
Ramabhadran, P. S.
Ramaswami, Gorur Srinivasamurthy, B.A.
Rankin, Richard Robert C.
Ranson, George Stanley.
Rao, Buntwal Rama.
Rao, Duggirala S. Pracasa.
Rao, Kurapati V. Subba.
Rao, Srinivasa Raghunatha.
Raymond, Harold Vallis.
Razdan, Suraj Narayan, B.Sc.
Readhead, James Templeman.
Reddi, Alandur Sundara R. G.
Reddy, Cattamanchi Ramalincha, B.A.
Redman, John.
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Scholes, George Hamer.
Sharp, Ernest Edward.
Smith, Harry John.
Squire, Charles Edward.
Strafford, Cecil.
Townend, Wilfred Thomas.
Urmston, James.
White, Ernest Saunders, B.Sc.(Eng.).

Associate to Associate Member.

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Davidson, George.
Outram, Frederick Colin.
Stone, Herbert John, M.C.
Vacy-Ash, William Maxwell, O.B.E.

Graduate to Associate Member.

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Bancroft, Herbert Douglas.
Bennett, Norbury Anderson, B.Sc.(Eng.).
Birtwistle, Marshall.
Brailsford, Fred, B.Sc.(Eng.).
Brown, John Carey, B.Sc.
Buckhurst, John Charles V., B.Sc.
Calkin, Alan Bernard, M.A.
Cameron, Thomas Tennant.
Child, Ivon Henry, B.Sc.(Eng.).
Cobb, Kenneth, B.Sc.(Eng.).
Colmar, Geoffrey Charles, B.Sc.(Eng.).
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Dudley, Harold.
Easton, Harold.
Eastwood, Donald Rex.
Gent, Albert.
Gibson, Henry Joseph.
Gillespie, Colin Arthur.
Gunn, George John T., B.Sc.
Handley, Eric Thomas.
Haskell, David Nissim, B.Sc.(Eng.).
Haslegrave, Herbert Leslie, B.A., B.Sc.
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Hirst, Alexander William C., B.Sc.(Eng.).
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Student to Associate Member.

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Roseway, Walter Norman, B.Sc.(Eng.).
Ryland, Leslie Francis, B.Sc.(Eng.).
Short, Harry Redfern.
Terroni, Teseo Bruno D., B.Sc.

Student to Associate.

Allan, Archibald Alexander.
Atkinson, William Scott.
Chapman, Leslie James.
Simpson, George Francis.
Wright, Hugh Crossley.

In addition, the following transfers have been effected by the Council:—

Transfers.

Student to Graduate.

Arkinstall, Leonard William.
Barnett, Ralph Ladislas.
Blake, Robert Austin.
Brand, Frank.
Brown, Archibald Leslie.
Brown, Guy Lawrence, B.Sc.(Eng.).
Brunner, Henry Theodore.
Buchan, Hector Kennedy, B.Sc.
Carr, Arthur Smith, B.Sc.
Christmas, Francis Thomas, B.Sc.(Eng.).
Damant, George Edward F., B.Sc.(Eng.).
Darby, William Joseph J.
de Fernandeze, Josie Augustine A.
Galley, Gordon William.
Gillett, Edward Arthur.
Graham, James Wilson.
Gresty, Ernest, B.Sc.Tech.
Harding, Alan Douglas.
Hughes, Frederick Kingsley, B.Sc.(Eng.).
Kenyon, James Eastwood.
Kyffin, John Jeffery N.
Linsley, Brian.
Macdonald, Montagu Frank.
McElwaine, James Graham, B.Sc.
Mackenzie, William Alexander, B.Sc.
Mackintosh, Philip Kilgour.
Medcalf, Wilfred Henry.
Miller, James Robert.
Morrison, James Latto, B.Sc.
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Accessions to the Reference Library.

ALLEN, H. S., *F.R.S.* Electrons and waves. An introduction to atomic physics.
8vo. 343 pp. *London*, 1932

BOLTZ, C. Everyman's wireless.
8vo. 335 pp. *London*, [1932]

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—— A technical description of Broadcasting House.
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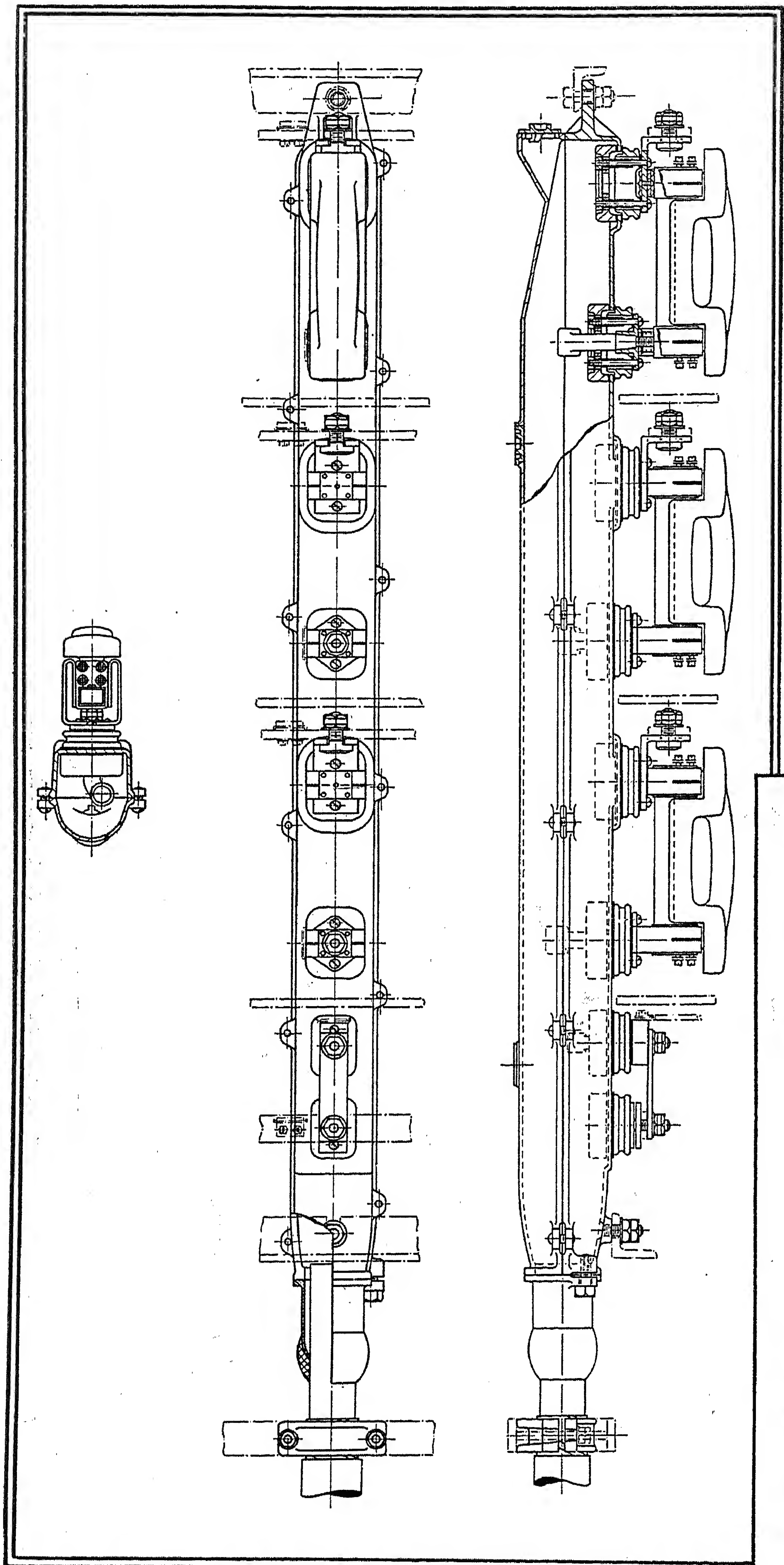

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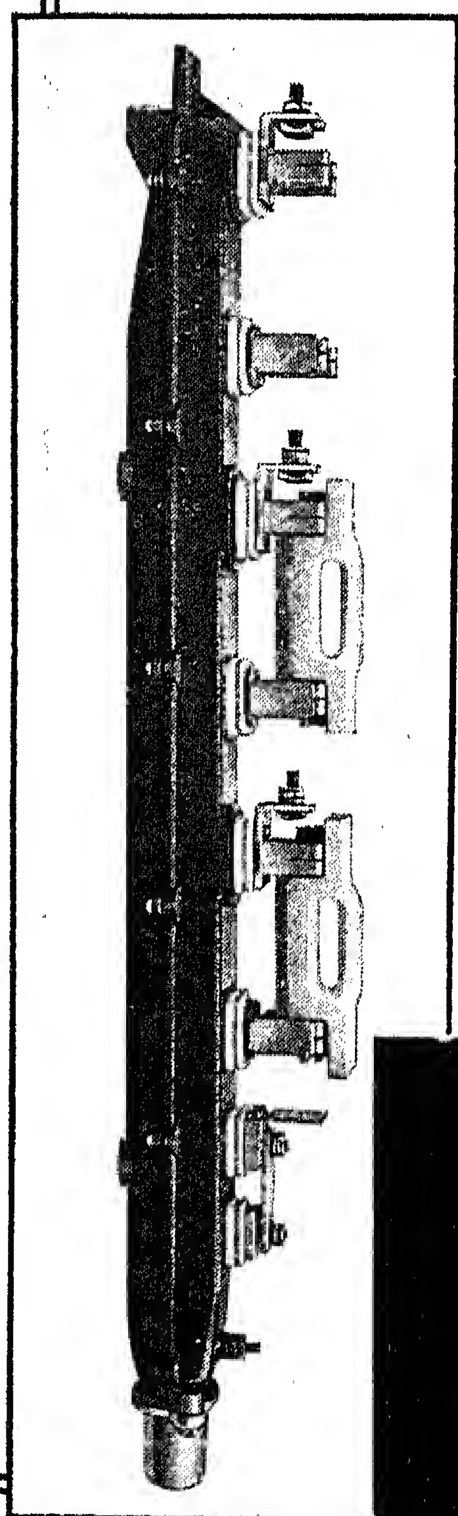

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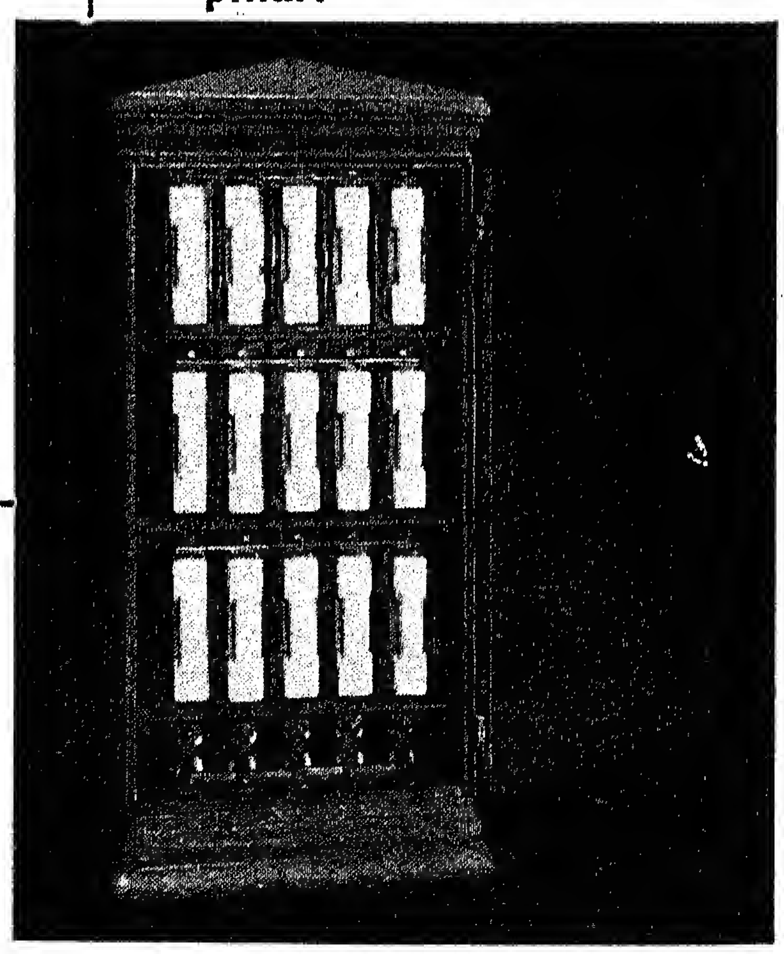

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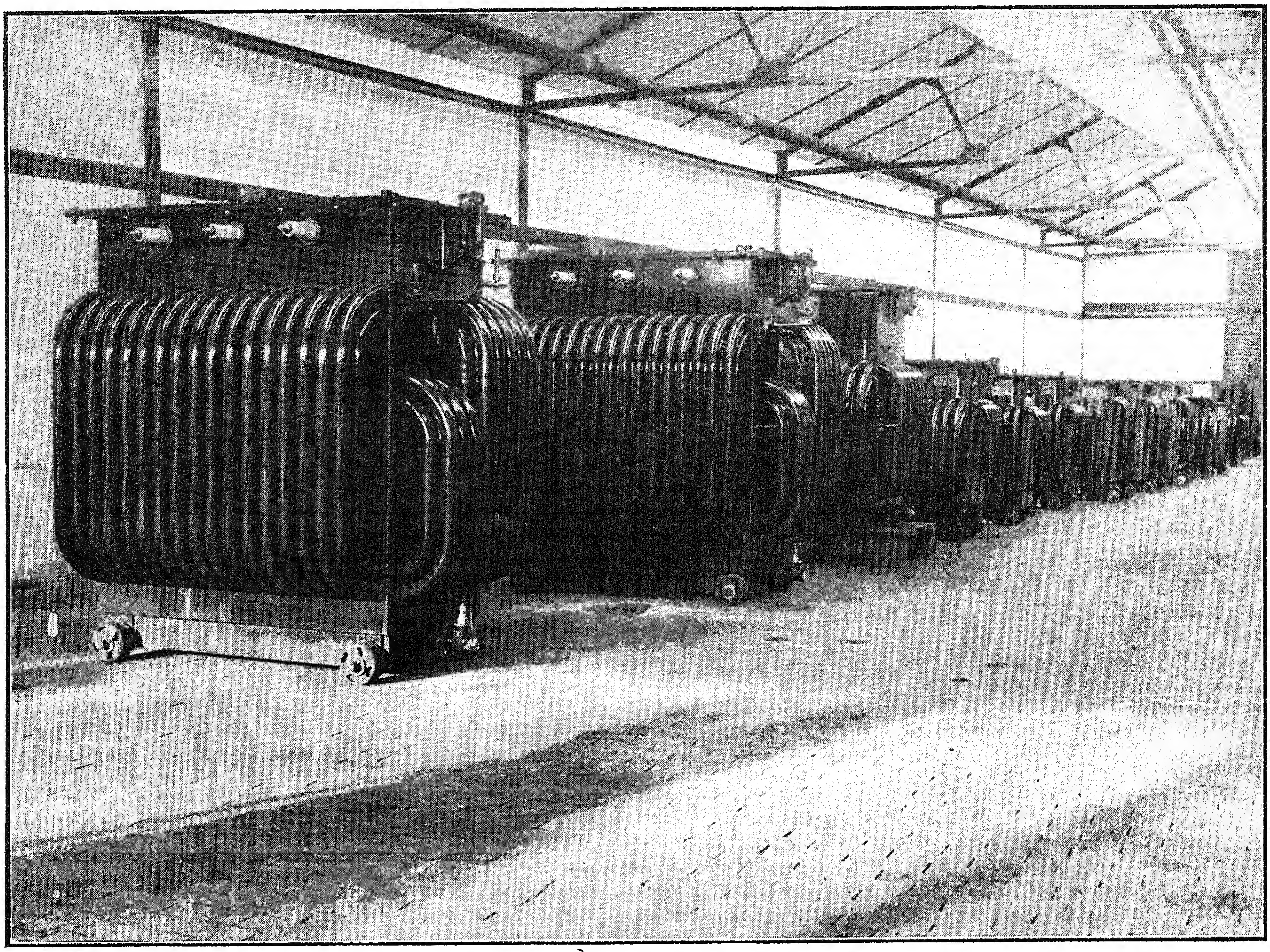

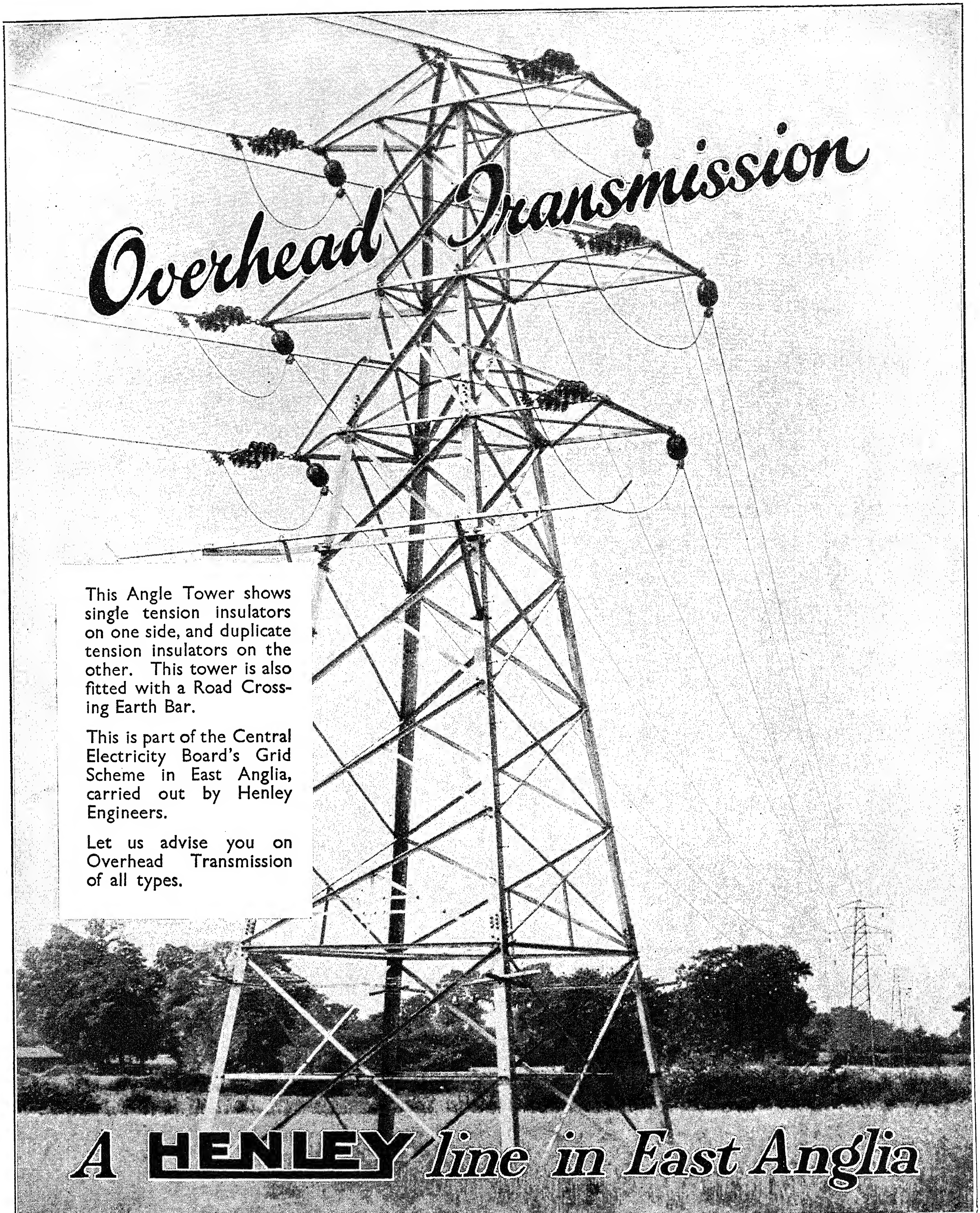
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